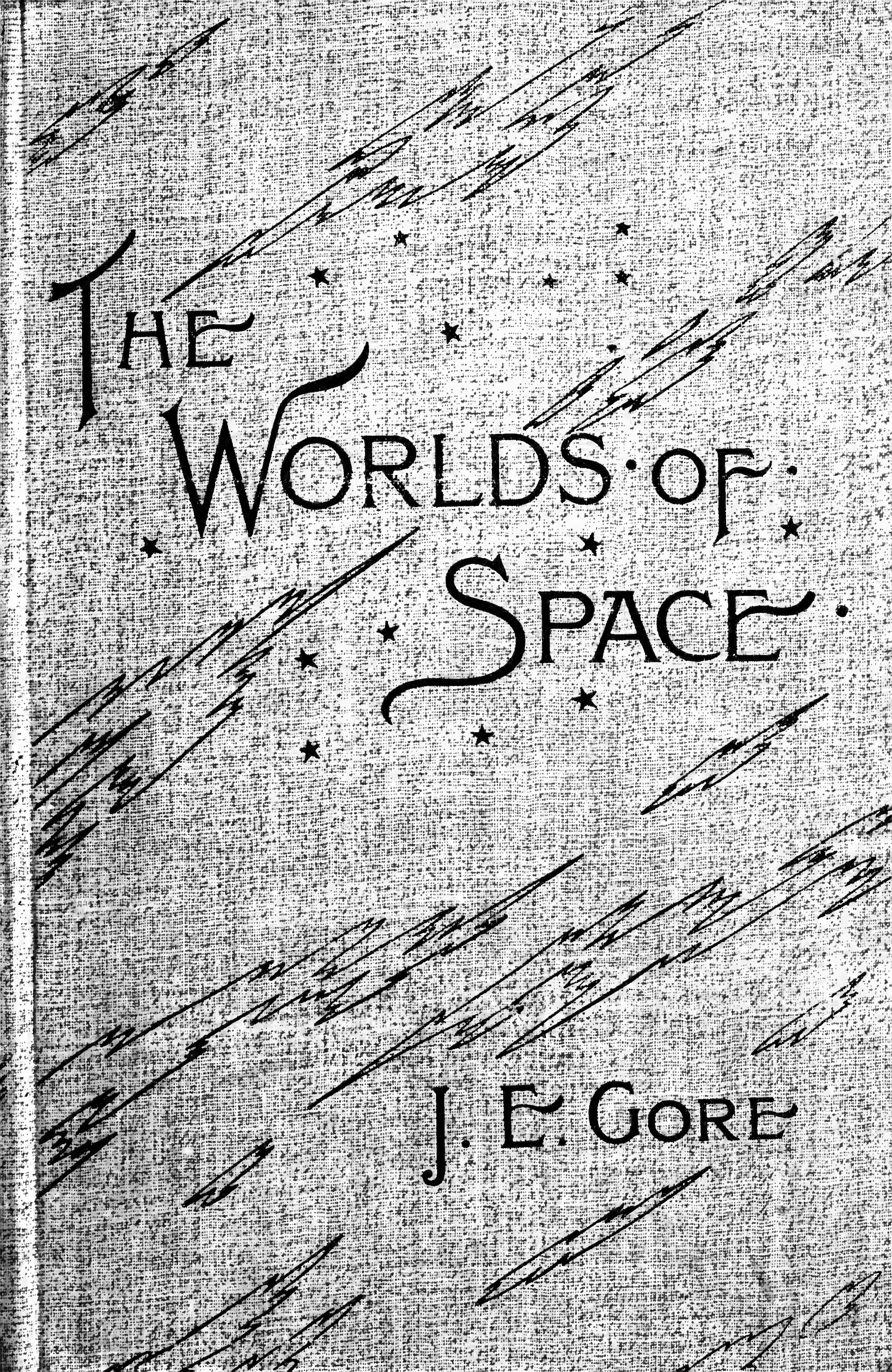
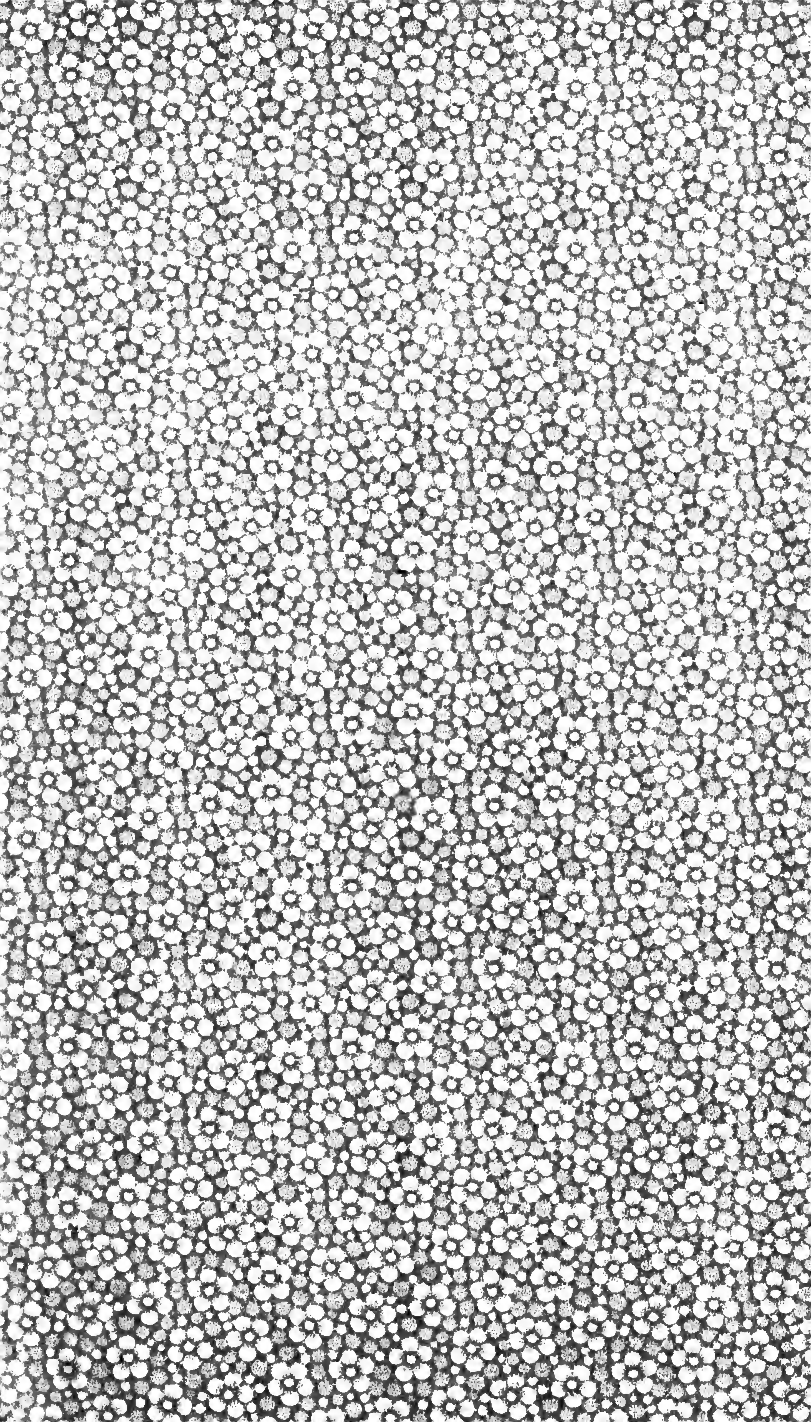


THE WORLDS OF SPACE

J. E. GORE



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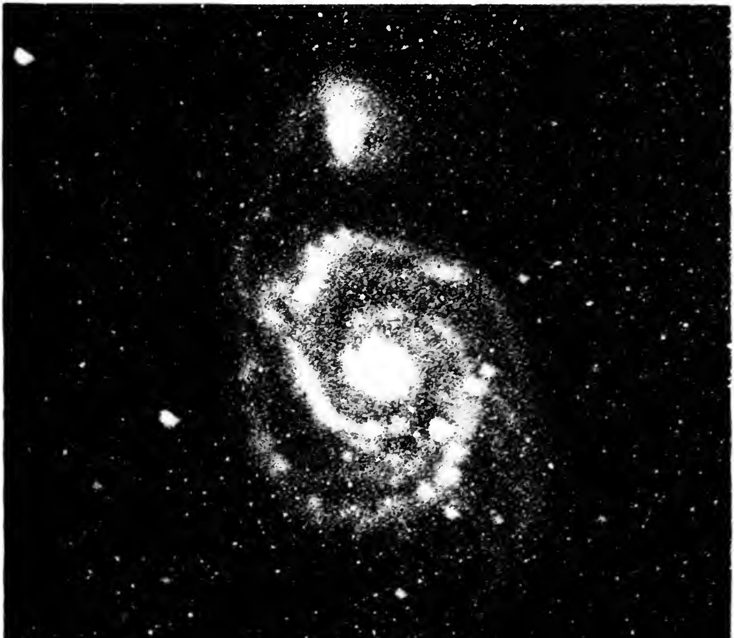

THE SPIRAL NEBULA 51 MESSIER IN CANES VENATICI. (P. 213.)

THE WORLDS OF SPACE

A SERIES OF POPULAR ARTICLES ON ASTRONOMICAL SUBJECTS.

BY

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> " In fields of air he writes his name,
> And treads the chambers of the sky;
> He reads the stars, and grasps the flame
> That quivers in the realms on high."—SPRAGUE.

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PREFACE.

THE following series of short popular articles on Astronomy and kindred subjects have been published in various magazines during the last three years, and deal chiefly with recent discoveries and advances in the science. My thanks are due to the Editors and Publishers of *The Parents' Review*, *The Monthly Packet*, *The Newbery House Magazine*, *Knowledge*, *The Gentleman's Magazine*, *The Sun*, *The Arts Monthly*, and *Indian Engineering*, for permission to reprint them, and to Dr. Roberts for some of his beautiful photographs. I have also to thank Mr. Ranyard for permission to reproduce some of the photographs which have appeared in *Knowledge*. Chapters xxix., xxx., xxxi., and xxxiii. originally appeared in *Indian Engineering*, a weekly Journal published in Calcutta by Pat. Doyle, C.E., F.R.A.S., etc.

J. E. G.

February 1894.

CONTENTS.

THE WORLDS OF SPACE.

I.

ARE THE PLANETS HABITABLE?

I DO not ask, Are the planets inhabited? That is a question to which an answer will probably never be vouchsafed to man. Even in the case of our nearest celestial neighbour, the Moon, the highest powers of our largest telescopes would fail to reveal the existence of any living creatures on its surface. Animals the size of elephants, or even as large as the gigantic saurians of geological times, would be quite invisible in the giant telescope of the Lick Observatory. Large cities, or buildings of great extent—if they existed—might possibly be discerned, and thus afford evidence of the existence of intelligent beings. But this only on the Moon. All the planets are much too distant to enable us to see anything but markings on their discs, these markings being only dimly visible on most of them, and possibly denoting, in some cases, the existence of oceans or large tracts of land on their surface. I say possibly, for only in one case—that of Mars—are these markings clearly enough defined, and sufficiently persistent in their character, to render it probable that they represent land and water. In the case of the Moon no definite indications of life on its surface have ever been detected. Indeed, the known absence of air and water is evidence enough to prove that life is impossible on the surface of our satellite. We must, therefore, abandon the hope that any improvement in our telescopes will ever show indications of life on the planets. There is nothing, however, to prevent us from making an inquiry into the *possibility* of the planets being habitable by living creatures such as we are familiar with. We may consider their position in the solar system with reference to the Sun, and their probable physical condition, so far as observation enables us to judge. We may in this way arrive at some conclusion, from analogy, as to the possible habitability of the planets and their satellites.

The ancient philosophers thought that the Sun itself might possibly be inhabited! Even in modern times this idea has been revived. Dr. Elliott in 1787 upheld this view, and on his trial at the Old Bailey for the murder of Miss Boydell, his friends maintained his insanity, and quoted as proof of their assertion the pages of his book, in which this opinion was expressed. Such an hypothesis as the habitability of the Sun does not seem worthy of serious consideration.

With reference to the planets, let us take them in order of their distance from the Sun, commencing with Mercury, the nearest to the solar orb. The mean distance of Mercury from the Sun, compared with that of the Earth, is about as 36 to 93, or 12 to 31. Hence, as light and heat vary inversely as the square of the distance, the average intensity of the Sun's light and heat on Mercury exceeds that on the Earth in the proportion of the square of 31 to the square of 12, or about 6⅔ times. Owing, however, to the elliptical shape of Mercury's orbit, its distance from the Sun varies in the ratio of 43 to 29. The intensity of the solar heat will therefore vary during the course of its short year—about 88 of our days—in the proportion of the square of 43 to the square of 29, or about as 9 to 4. This violent change of temperature, which takes place in the short period of six weeks (half the period of revolution) is, of course, strong evidence against the hypothesis of any life existing on the surface of Mercury. Certainly none of the larger animals that we are familiar with could possibly withstand a heat of nine times the intensity experienced in the Earth's equatorial regions.

The period of rotation of the planet on its axis, or the length of its days, has always been a matter of much uncertainty. Owing to the position of its orbit its distance from the Earth is subject to great fluctuations. When near "inferior" conjunction, or on this side of the Sun, it shines at its brightest, but in this position it only appears in the form of a crescent, like the Moon when a "few days old." When near "superior" conjunction, or beyond the Sun, it shines with nearly a full face, but then the diameter of its disc is so small—owing to its great distance from the Earth—that any markings which may exist on its surface are only seen with much uncertainty. The few occasions on which Mercury is visible in the morning or evening twilight also render observations of its surface markings a matter of great difficulty.

From observations of some spots on its surface, made by the German astronomer Schröter towards the close of the eighteenth century, Bessel concluded that the planet rotated in about twenty-four hours and fifty-three seconds, on an axis inclined about 70° to the plane of the planet's orbit. If this were the case the seasons on Mercury would not differ much—except in their length—from those of the Earth, and possibly near the poles, the planet's "arctic" regions, the temperature might be sufficiently cool to admit of some forms, at least, of animal life. The near coincidence of the period found by Schröter and Bessel with the length of our day looks, however, suspicious. If Schröter observed Mercury on several consecutive evenings (or mornings) at nearly the same hour, as he probably did, and watched the same spot on its surface, it is easy to see that—even if the planet had no rotation on its axis—he might have concluded, with some show of plausibility, that the period of rotation was about twenty-four hours. He might, of course, have concluded also that the rotation took place in some aliquot part of twenty-four hours, say, twelve hours, or six hours, but this, from the analogy of the other "terrestrial" planets (Venus, the Earth, and Mars), seemed an improbable hypothesis. In later years further observations of Mercury were made by the astronomers Bülow and Dr. L. de Ball, but their results seem to have still left the matter an open question.

The problem was again attacked in 1881 by the famous Italian astronomer Schiaparelli, who, recognizing that the uncertainty of the results derived from the earlier observations was in a great measure due to the unfavourable visibility of Mercury in the morning or evening sky, resolved to observe the planet by an entirely new method. This new departure consisted in observing the planet in the *day-time* by means of an 8-inch refractor, and (latterly) an 18-inch refractor. Of course the exact position of the planet in the sky at any time can be easily computed, and the telescope pointed to its exact place. From the year 1881 to November 1889, Schiaparelli succeeded in observing Mercury on 150 days. On one occasion he observed the planet when distant from the Sun only six diameters of the solar disc! a good proof of the excellence of the instrument as well as the keen sight of the observer. Schiaparelli took the precaution of observing the planet not merely at the same hour on each day, but at *various* hours on several successive days. On these occasions he could not detect any appreciable change in the position of the spots observed, which apparently remained stationary for long periods at a time. He, therefore, arrives at the remarkable conclusion that the planet rotates on its axis in the same time that it revolves round the Sun—namely 88 days, with its axis of rotation nearly at right angles to the plane of the planet's orbit. This remarkable and wholly unexpected result is, however, not without precedent in the solar system. We have a similar case in our moon, which rotates on its own axis in the same time that it revolves round the Earth, in the satellites of Jupiter, in the outer satellite of Saturn, Japetus, and probably also in the satellites of Mars.

Assuming the reality of Schiaparelli's discovery, let us see what the result will be of this equality between the period of Mercury's revolution round the Sun, and that of its rotation on its axis. Some may suppose that the length of the day on Mercury will be simply increased in length to 88 times the length of our day, with a regular alternation of day and night. But this is not exactly what will happen. In the case of our Moon, the length of its day (that is, day and night) is certainly equal to its period of revolution round the Earth; but then the Moon revolves round the Earth, not round the Sun; and although it persistently turns the same face towards the Earth, every portion of its surface will, in the course of a lunar month, be turned towards the Sun. In the case of Mercury, however, as its rotation period is equal to its period of revolution round the *Sun*, the planet will constantly present the same face to the Sun, as the Moon does to the Earth. The result of this of course will be, that on one side there will be constant day, and on the opposite side perpetual night. At first sight the arrangement would seem to render both sides of the planet uninhabitable. A little further consideration, however, will show that along a narrow zone near the circle dividing the light from the dark side, an inhabitant of Mercury would have the Sun constantly near his horizon, and considering the great intensity of the solar heat on Mercury, compared to that which we experience, this arrangement might serve to render a small zone of Mercury's surface habitable by some forms of life.

Owing to the elliptical shape of the planet's orbit round the Sun, its velocity will vary to a considerable extent. We may, however, conclude, from analogy, that the rotational motion on its axis is uniform. This difference in the regularity of the two motions will, of course, give rise to a "libration"—similar to the Moon's libration—which will have the effect of bringing a portion of the dark side of Mercury periodically into the sunlight, and will thus diminish the area of the planet's surface which is shrouded in perpetual night. About three-eighths of the total surface will for ever remain in darkness, three-eighths in perpetual sunshine, while the remaining one-fourth will have alternately day and night. In fact, an inhabitant living near the mean boundary line, and on the planet's equator, would have 44 days of sunshine, and 44 days of night or twilight. A little further in, on the bright side, there would be perpetual day. A little further in, on the dark side, there would be perpetual twilight; and further in still eternal night would reign. Owing to the low altitude attained by the Sun near the boundary line, its intense heat and light would of course be much mitigated, so that probably this region of the planet's surface may be comparable with the temperate zones of the Earth. Of course in the centre of the bright or dark side we cannot imagine any life could exist; but at a little distance from the dividing zone, we may suppose the existence of a tropical zone towards the bright side, and of an arctic zone towards the dark side.

It may be asked, How did this slow rotation of Mercury probably originate? It has possibly been caused by tidal friction acting through long ages on the oceans which we may suppose to exist on the surface of the planet. If our Moon was originally covered to a large extent with water, the great mass of the Earth—about 80 times the Moon's mass—

combined with the small force of gravity on the Moon (about six times less than gravity on the Earth), would have produced enormous tides, which would, by their friction, have gradually reduced the velocity of its rotation, thereby lengthening the day, and eventually bringing it into equality with the period of its revolution round the Earth. In the case of Mercury, its proximity to the Sun, combined with its small mass, would produce far greater tides than those on the Earth, and the resulting friction would have operated powerfully in reducing the rotation velocity of so comparatively small a planet.

The evidence in favour of an atmosphere round Mercury seems inconclusive. Of course we cannot imagine the existence of life on a planet utterly devoid of an atmosphere, but if the atmosphere differed very much in constitution from ours, life—as we know it—would not be possible on the surface of such a planet. From appearances observed on Mercury when in the crescent form, Schröter inferred the existence of a dense atmosphere. The correctness of this conclusion has been doubted, but some of Schiaparelli's observations indicate that an atmosphere and water probably do exist on the planet. If this be so, the water is probably at or above the boiling-point near the centre of the bright side, and perhaps frozen solid on the dark side.

In the case of Venus, we have a planet not differing much from the Earth in size, its mass being about four-fifths that of our globe. It is of course much nearer the Sun, and the intensity of the solar light and heat on Venus must be about double what we experience. The period of rotation on its axis, or the length of its day, is somewhat uncertain. Schröter and De Vico made it about $23\frac{1}{3}$ hours, and observations by Cassini and Mädler appear to confirm this result; but the exact period would seem to be still an open question. Still greater uncertainty is attached to the position of its axis of rotation. Some observers make its inclination to the planet's orbit plane about $73\frac{1}{2}°$; but this has not been confirmed. Denning finds the markings on Venus much more difficult to see than those on Mercury, usually, indeed, of almost evanescent faintness. Under these circumstances the difficulty of determining the period of rotation, and the position of the planet's axis, will be easily understood.

That Venus possesses an atmosphere somewhat similar to our own, and of considerable density, seems beyond doubt. The arc of light seen round the disc of Venus before its entrance on the Sun in the recent transits clearly shows refraction of light by a gaseous envelope. Spectroscopic observations made by Professor Young during the transit of 1882 showed unmistakable indications of an atmosphere surrounding the planet; and the observations of Cassini, Mädler, Noble, Schröter, Secchi, and others all tend to confirm the evidence afforded by the prism.

Indeed Neison (Neville) considers that it has probably double the density of our own.

An attempt has been made to explain the remarkable brilliancy of Venus by supposing that the sunlight is reflected from a persistent cloudy stratum surrounding the planet. This stratum would of course have the effect of shielding the planet's surface from the intense heat and glare of the Sun; but it would also suggest an almost constant rainfall—a condition rather unfavourable to the existence of animal life.

If we suppose the inclination of the axis to the orbit plane to be about the same as that of the Earth, the seasons on Venus will not differ much from ours except in duration, the length of the planet's year being about 225 days, while ours is 365.[1] The shape of Venus's orbit is nearly circular, so that the planet would not, as in the case of Mercury, experience any violent changes of temperature. Owing to the increased intensity of the solar heat on Venus we cannot suppose that its equatorial regions can form the abodes of life; but possibly in the regions surrounding the planet's poles the temperature may be sufficiently cool to admit of some forms of animal existence. Indeed, some observations by Gruithuisen and Trouvelot seem to indicate the presence of solar snow-caps, similar to those observed on Mars; but of

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[1] Schiaparelli thinks that the rotation of Venus is similar to that of Mercury. If this be so, the above remarks with reference to the planet's seasons will not hold good.

course observations of this kind are open to considerable doubt, and the faintness of the markings seen on Venus leaves the question of its physical condition one of much uncertainty.

Passing over the planet Earth, which we know to be inhabited by various forms of life—even in the heart of "Darkest Africa"—we come now to the "red planet" Mars. Of all the planets of the solar system, Mars presents the greatest resemblance to the Earth. The markings on its surface, which have been well observed and mapped, clearly indicate the presence of land and water on its surface. From the observed motion of these spots, the period of the planet's rotation on its axis, or the length of its day, has been accurately determined to a fraction of a single second. This period amounts to 24 hours, 37 minutes, 22⅔ seconds, differing but little therefore from our own day. The inclination of the axis of rotation to the plane of the planet's orbit is, according to Schiaparelli, 65° 48′, or nearly the same as that of the Earth. The seasons therefore on Mars must be similar to ours, but of longer duration; the length of the planet's year being about 687 of our days. Observations seem to show that the atmosphere of Mars is not so dense as ours.

That the planet has an atmosphere is, however, beyond all question. This is proved by the presence of snow-caps, by the occasional observation or blurring of the markings by clouds, and by the stronger evidence of the spectroscope, which shows "air lines" in the spectrum, evidently due to the presence of watery vapour in a gaseous envelope surrounding the planet. Considering, however, the distance of Mars from the Sun—greater than that of the Earth in the proportion of 47 to 31—the intensity of the Sun's heat will be much less than the Earth receives. Indeed, it would be reduced to less than one-half of what we experience. Still at the planet's equator, and under a vertical sun at noon, the temperature may perhaps be sufficiently high to support some forms of life. Curiously enough most of the land on the planet's surface seems to be distributed along the planet's equatorial regions, the greater portion of the water surface being collected round the north and south poles. The areas of the land and water on Mars are about equal, whereas with us the water surface exceeds that of the land in the proportion of 3 to 1. The land and water on Mars are also more evenly distributed than on the Earth, and this would have the effect of equalizing the temperature, and would perhaps make the conditions of life more favourable than we might at first sight be disposed to imagine. Mars must, however, be an undoubtedly cold planet, and the question why its surface is not more covered with ice and snow than it is, is one which has not yet been satisfactorily answered. Possibly some special constitution of its atmosphere may mitigate the severity of its climatic conditions. I am disposed to think, however, that if life ever existed on the surface of Mars it has now become extinct.

Of the habitability of the minor planets we know almost absolutely nothing. Their small size, however, and their great distance from the Sun would lead us to conclude that the existence of any forms of life on their surface is at least highly improbable.

Of the large planets, Jupiter, Saturn, Uranus, and Neptune, observations seem to show that they are still in a highly heated condition, and, therefore, quite unfit for the support of any form of animal life. Neptune, however, appears to be cooler than the others, and possibly its internal heat may be only sufficient to raise the temperature of its surface to a point fitted for the maintenance of life. But this is of course merely conjecture. The heat which Neptune receives from the distant Sun is, however, certainly very small—about $\frac{1}{900}$ of the intensity on the Earth—too small, indeed, to have any appreciable effect in rendering the planet habitable.

It is almost universally admitted by astronomers and physicists that the Sun is gradually cooling down. That it was hotter in geological times seems clearly indicated by the coal-beds found in the arctic regions, and their existence even in the British Islands is evidence in the same direction. In those far distant times Mars was possibly a habitable and inhabited planet, but has now probably passed the life-bearing stage of its existence, through which our earth is at present passing. When, in the course of ages, the Sun has still further cooled down, all life will probably cease to exist on our globe, and in that remote epoch Venus will probably form the theatre of life. If life now exists near its poles it will then probably extend to its equator, and the cloudy canopy, in which it now seems to be shrouded, will then, owing to the diminution of the solar heat, be gradually dissolved, and the glories of the starry heavens will be revealed to its wondering inhabitants. Later still, in the march of time, life will die out on Venus also, and then Mercury will become cool enough—even at the centre of its sun-lit side—to be inhabited by animal life. At last the solar heat being reduced to its minimum, life will cease on Mercury also, and the Sun himself, perhaps, will "roll through space, a cold and dark ball." Such may possibly be the course of life in the solar system. As a writer has well said, "When the birth, the progress, and the history of sidereal systems are considered, we require some other unit of time than even the comprehensive one which astronomy has unfolded to our view. Minute, and almost infinitesimal as is the time which comprises the history of our race, compared with that which records the history of our system, the space even of this latter period forms too limited a standard wherewith to measure the footmarks of eternity."

II.

TERRESTRIAL AND SUN-LIKE PLANETS.

THE planets forming the solar system may be divided into three groups, viz.: 1. The Terrestrial Planets, including Mercury, Venus, the Earth, and Mars. 2. The Minor Planets, or asteroids, as they are sometimes called, which form a ring or zone of small planets revolving round the Sun between the orbits of Mars and Jupiter; and 3. The large planets, sometimes called the Major Planets, which include Jupiter, Saturn, Uranus, and Neptune. The Terrestrial Planets are so called because they present many points of resemblance to the Earth. The length of the day in each—except perhaps in Mercury[1]—is probably nearly the same. The inclination of the planet's equator to the plane of its orbit is in all very similar. Each probably possesses an atmosphere of analogous composition to our own; and each has

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[1] Professor Schiaparelli, the eminent Italian astronomer, concludes from his own observations that Mercury rotates on its axis in the same time that it revolves round the sun, viz. about 88 days.

probably its surface diversified by land and water. In the case of the Earth we have the equatorial regions, although very warm, fairly habitable by living creatures, while the regions immediately surrounding the poles are probably devoid of all animal life. This state of things may possibly be reversed on Mercury and Venus. In these planets, where the total light and heat are so much greater than we receive, the equatorial regions are most probably uninhabitable owing to the intense heat, while the regions round the poles may be sufficiently cool to form the abodes of life. This is very probably the case with Venus in particular, where the total heat received from the Sun is not more than double the amount we have on Earth. The excessive brightness of its surface—found by one astronomer to be about ten times as bright as the surface of the full moon! and reflecting, according to Zöllner, as much light as freshly fallen snow—would imply that most of its light is reflected from a persistent stratum of dense clouds which would of course reflect considerably more sunlight than the surface of the planet itself. This heavy cloud stratum would mitigate to a considerable extent the intensity of the solar rays, and if sufficiently dense and persistent, then to the inhabitants of Venus, if any there be, the Sun and stars will for ever remain unseen by them, for, like a pall, the cloudy canopy covers all. Mercury must, of course, be very much hotter than Venus, but still its polar regions may perhaps be tolerably cool, and possibly physical conditions, of which we know little, may serve to moderate the intense heat to which its surface is subjected. As, however, Mercury is much less luminous than Venus its atmosphere is probably not so cloud-laden. This is confirmed by the observations of Mr. Denning, who finds that the markings on Mercury are much more easily seen than those on Venus, and Zöllner found that it reflects only 12½ per cent. of the solar rays, very similar therefore, in this particular, to the moon, which reflects about 17 per cent. of the incident solar light.

Mars we know possesses land and water, an atmosphere, and length of day similar to ours, and seasons which, though of longer duration, are not widely different from those which we experience. Its supply of heat is of course much less, but still its equatorial regions, assisted by special physical conditions, may possibly be much warmer than we might at first sight be disposed to imagine. The more equable distribution of land and water on its surface, which we know exists on Mars, would also tend to equalize the temperature, and possibly render the planet—at least in regions near the equator—a fitting abode for some forms of animal life. Probably, however, a slight excess of heat would be more favourable to animal existence than a deficiency of solar warmth, and on the whole I am inclined to believe that of the planets of the Solar System, Venus is the one most likely to be inhabited by sentient beings like ourselves.

Next to Mars, we have a zone or ring of small planets, of the physical conditions and habitability of which we know little or nothing. All we know about them is that they are very small, and therefore unlike the terrestrial planets on the one hand, and the "giant" planets on the other, between which groups they are situated. It was suggested by Olbers that they may possibly form the fragments of a larger planet which has been shattered into pieces by the force of some internal explosion. This somewhat plausible hypothesis at one time gained some credence, but there are many objections to the theory, and it is not now generally accepted by astronomers.

Professor Vaughan has lately suggested as a more probable origin the collision of two planets of "not very unequal size or mass." This would become possible when, from a long series of perturbations, the orbits became very eccentric, and the aphelion of one orbit came into conjunction with the perihelion of the other, and near the intersection of their planes. Professor Vaughan points out that the distances of the satellites of Saturn from their primary "show a near conformity to geometrical progression" (with a common ratio of 1·30756). He thinks that apparently four satellites are missing from the Saturnian system, and that possibly these may have become asteroids.

This seems the converse of the hypothesis which has been advanced, that the satellites of Mars were originally minor planets, which, coming too near Mars, were captured by it.[1]

When we come to examine the large planets we find a condition of things totally different from the "terrestrial" planets. They are all very large bodies; very much larger than the Earth in volume; very much lighter in density than the Earth; rotating on their axes much more rapidly, and surrounded by atmospheres much more extensive than our own. Considering the small specific gravity of these gigantic planets, we are compelled to consider that their physical condition must be wholly different from that of the Earth. The density of Jupiter does not differ much from that of the Sun. That of Saturn is about 0·66 (water being 1). That of Uranus about the same as water, and that of Neptune somewhat less. Considering their enormous absolute mass, in the case of Jupiter 312 times, and in the case of Uranus about 14½ times the mass of the Earth, and that this mass must act with great force to compress the materials from the surface towards the centre of the planet, we see at once that their condition must be utterly unlike that of the Earth. In the case of the Sun its small density is simply and satisfactorily explained by its intense heat, which is sufficient to maintain its surface in the gaseous state,

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[1] *Combtes Rendus*, Nov. 28, 1887.

and, according to Helmholtz and Sir W. Thomson, in the fluid state even to its centre. Unless we assume a somewhat similar state of things in the large planets, we are unable to explain why their density should be so small.

Let us see what evidence observation affords in support of this view. The "belts" of Jupiter are familiar to almost every one, at least by name. These are darkish markings on the planet's apparent surface, usually parallel to the planet's equator, and may be seen with telescopes of moderate power, though, of course, large instruments are necessary to examine their details satisfactorily. These belts are not permanent features, but are subject to great and rapid changes, both in form and position. Now if we consider the great distance of Jupiter from the Sun—more than five times greater than that of the Earth—and that the heat derived from the great central luminary is enfeebled in the ratio of the square of the distance, we see how little effect the Sun's heat can possibly have in producing changes in Jupiter's atmosphere. Some other cause must therefore be at work, capable of causing changes of such magnitude as to be visible at the vast distance which separates the Earth from Jupiter. Mr. Ranyard, the well-known astronomer, has attempted to show that spots on Jupiter are more prevalent when spots on the Sun are most numerous, and he considers that possibly both phenomena may be due to the same or similar cosmical cause. This view seems to be confirmed by Mr. Browning, who finds that the red colour of the belts coincides with the epoch of Sun spot maxima. An enormous reddish spot of elliptical shape, and measuring some 25,000 miles in length by 7000 in breadth, has been visible for some years past on the southern hemisphere of the planet. It was most clearly visible in the year 1882, which was near an epoch of Sun spot maximum. In 1884 it was very faint and difficult to be seen, but it afterwards partly reappeared, and in 1885 was observed to have its central portion apparently covered with a white cloud, thus giving it the appearance of an elliptical ring. Observations in 1888 showed it still visible, though faint. Perhaps the most remarkable fact connected with it is, that the period of Jupiter's rotation on its axis, computed from observations of this spot, has been slowly increasing since the spot first became visible. Now, from the analogy of the Earth and Mars, we may conclude that the rotation period of Jupiter is uniform, at least so uniform during a period of nine years, that no observations could detect any change. The observations therefore of this red spot would seem to indicate that it has a drifting motion of its own over the surface of the planet, and this, combined with the changes in appearance it has undergone, and its enormous magnitude, would imply the action of forces which have no parallel on Earth.

It must be added, however, that some astronomers —including Professor Hough and Mr. Lynn—are of opinion that the red spot forms a portion of the actual body of the planet, and that consequently the increase in the rotation period is real, and not merely apparent! As the solar heat is evidently incapable of producing the observed changes in the belts and markings on Jupiter, there seems to be no escape from the conclusion that the forces at work have their origin within the globe of the planet itself. Some curious observations have been made of Jupiter's satellites when transiting the disc of their primary. Satellite III. has often been seen quite as black as the shadow it casts on the face of the planet! On one occasion the American astronomer Bond saw this satellite as a black spot lying between its own shadow and the shadow of I., and not to be distinguished from either shadow except by its position. The shadow of I. was observed to be very faint at Stonyhurst in November 1880, and Gorton saw it grey on one occasion, which seems to imply that the planet has some intrinsic light of its own.

In the case of Saturn we have a somewhat similar condition of things. "Belts" are also visible here, but of course, owing to its greater distance from the earth, any changes which may occur in them—although probably on quite as gigantic a scale—are not so easily observed as those of Jupiter. The markings on

Saturn are however undoubtedly variable both in size and position, and—like those of Jupiter—of enormous dimensions. As the mean distance of Saturn from the Sun is greater than that of Jupiter in the proportion of 886 to 483, or about 11 to 6, we have the intensity of the solar heat further diminished in the ratio of the squares of these numbers, or as 121 to 36; or in other words, the intensity of the heat derived by Saturn from the Sun is less than one-third of that received by Jupiter. We see therefore how small an effect the Sun's heat can have in producing changes in Saturn's atmosphere. Considering also the very small density of Saturn's globe—not much more than half that of Jupiter—and about that of walnut wood, the argument in favour of inherent heat in Jupiter is further strengthened in the case of the "ringed planet."

The immense distance of Uranus from the Sun prevents us from obtaining much evidence respecting its physical condition, and this remark applies of course with greater force in the case of Neptune. Traces of belts have, however, been recently detected on the disc of Uranus, with some of the monster telescopes of modern days, and observations of these markings seem to indicate that the period of rotation does not differ much from ten hours, as in the case of Jupiter and Saturn. Mr. Taylor has recently examined the spectrum of Uranus with the aid of Mr. Common's five foot reflector at Ealing. He finds that "the most striking features are four dark bands in the orange, green, greenish-blue, and blue respectively, and bright flutings in the red, orange, and green. No trace of any solar lines, or of any narrow lines, could be seen in the spectrum." The latter have, however, been detected by Dr. Huggins, by means of photography and an exposure of two hours. These were found in the violet end of the spectrum, whereas the bright flutings seen by Mr. Taylor were near the red end. Mr. Taylor satisfied himself that the bright flutings were not due to effect of contrast with dark lines, and he found that the Sodium line D was absent from the spectrum. He concludes that "the presence of the bright flutings in the spectrum of Uranus indicates that we must considerably modify our ideas as to the physical constitution of this planet (and most probably of Neptune also), for there can be very little doubt that it is to a large extent self-luminous." Mr. Taylor's observations were confirmed by Messrs. Bicknell, Crossley, and Fowler, using the same instrument. From these observations, Mr. Ranyard considers "that the natural spectrum of Uranus may only be that of a warm or red-hot body shining with long wave lengths. Therefore at the violet end we might have only the solar light, and at the red end an additional light from the body of the planet." It should be stated, however, that observations at the Lick Observatory seem to show that the light of the planet is merely reflected sunlight. The spectra of Jupiter and Saturn also present some peculiarities different from that of ordinary reflected sunlight, but not in so remarkable a degree as that of Uranus.

If we consider the members of the Solar System to have been originally formed from the condensation of an enormous heated nebulous mass, as in Laplace's Nebular Hypothesis, or by some other process of evolution, as many astronomers suppose, then it would follow that the large planets would—owing to their greater size—cool down more slowly, and for this reason we should expect to find that the large planets are still hotter than the Earth. We know from the evidence of mines, deep Artesian wells, volcanoes, and hot springs, that even the Earth, which has long since cooled down on its surface, still retains in its interior some of its primeval heat. In the large planets the original heat probably still exists even on their surfaces. We must, however, conclude that, although hotter than the Earth, they are much cooler than the Sun, which, owing to its vastly greater size, of course parts with its heat still more slowly. If we consider that the Sun's heat is due, as seems highly probable, to the shrinkage or condensation of its mass, we may also conclude that the shrinkage of Jupiter's mass must produce a certain amount of heat, which may be sufficient to keep its surface in at least a red-hot state. In fact, there would seem to be evidence in favour of the theory that these immense planets are in an intermediate state between the Sun and the "terrestrial" planets. If we look upon them as possessing inherent heat, we may suppose them also to have some intrinsic light of their own in addition to the light reflected from the Sun, unless, indeed, they are merely at a dull red heat which would emit but little light. If, however, they do emit any light, we might naturally expect to find that these larger planets would shine with greater brightness in our night skies than would be due to their relative distances from the Sun and Earth. Let us see what evidence observation affords us on this point. From photometric observations Zöllner found that the reflective power of Mars, or its "albedo," as it is called by astronomers, is 0·2672, or, in other words, that Mars reflects about 26¾ per cent. of the solar light falling on it. For Jupiter he found an "albedo" of 0·62, that is, a reflective power of 62 per cent. (that of white paper being 70), or more than double that of Mars, and nearly four times that of the Moon, of which he found the albedo only 0·1736. We must recollect, however, that the reflected light from Mars is absorbed to some extent by the planet's atmosphere; in fact a double absorption takes place, first in passing from the Sun through the atmosphere to the planet's surface, and then back again to the Earth. Making due allowance for this, however, it is evident that the brightness of Jupiter is considerably greater than that of Mars, and if we consider that a large portion of Jupiter's disc is darkened by belts and spots, we must conclude that the brighter parts of its surface must be very bright indeed—probably considerably brighter than snow.

In the case of Uranus compared with Jupiter, we have the mean distances from the Sun represented by the numbers 5·20 and 19·183 respectively, and their apparent diameters 4″ and 46″. From these data I find that Jupiter should be 1799 times brighter than Uranus. Now the stellar magnitude of Uranus when in opposition being 5·46, and that of Jupiter 2·52, according to Zöllner, we have the observed light of Jupiter equal to 1556 times the light of Uranus. Hence we have the albedo of Uranus (assuming Zöllner's value for Jupiter) equal to $\frac{1799}{1556} \times 0{\cdot}62 = 1{\cdot}15 \times 0{\cdot}62 = 0{\cdot}71$, a brightness equal to that of white paper!—a result which certainly points to intrinsic light in this distant planet, and obviously tends to confirm the spectroscopic evidence of heat sufficient to dissociate water.

If we agree to consider the large planets as being in a highly heated condition, we must of course abandon the idea that they can possibly form the abodes of life, and the description of some writers of the surpassing splendour of Saturn's sky, with its rings and satellites, as viewed by an inhabitant of Saturn, must be given up as a pleasant dream. The case may, however, be very different with the satellites which circle round them, and these giant planets may very possibly play the part of miniature suns to their attendant family of moons. Indeed Saturn's system seems to form a sort of miniature of the solar system. It has eight satellites, corresponding to the eight larger planets revolving round the Sun, and a system of rings—now generally admitted to consist of a swarm of minute satellites—similar, even in its divisions, to the zone of minor planets revolving between the orbits of Mars and Jupiter.

Seen from Jupiter's nearest satellite, the planet's enormous globe would show a disc of about 19° in diameter, or over 1300 times the area of the full Moon. From the other satellites his disc would vary from 12° to about 4°. From Mimas, the nearest satellite of Saturn, the planet would present a disc of no less than 33° in diameter, and with the encircling ring system would afford a considerable amount of light, and form a magnificent spectacle in the midnight sky of Mimas. Seen from the satellites of Uranus the planet would show a disc varying from $15\frac{1}{2}°$ to 5° in diameter.

We see, therefore, that the amount of light, and possibly heat, received by the satellites of these systems from their primary may possibly form a considerable addition to the scanty supply received from the Sun, and that the existence of some forms at least of life on their surface may be more probable than their great distance from the Sun would at first sight lead us to imagine.

III.

LIFE IN OTHER WORLDS.

The question is often asked, Are the stars inhabited? To this we can confidently answer, No. The stars themselves are certainly not habitable by any forms of life with which we are familiar. That the stars are luminous incandescent bodies, similar to the Sun, seems almost self-evident. That they shine by their own inherent light, and not by light reflected from another body, like the planets of the Solar System, is a fact which scarcely needs demonstration. There are no bright objects near them from which they could derive their light, and they are too far from the Sun to obtain any illumination from that source. But if any proofs were necessary, we have the evidence of the spectroscope, which shows unmistakably that their light emanates from incandescent bodies. Many of the stars show spectra very similar to that of the Sun. The light of others, although differing somewhat in quality when analyzed by the prism, indicates clearly that they are at a very high temperature—in many cases, indeed, suggesting that they are actually hotter than the Sun. It may be objected, however, that in the case of binary or revolving double stars, the smaller component may possibly shine by light reflected from the brighter star. Indeed this has been suggested in the case of Sirius and its faint companion. But I have shown elsewhere[1] that, if the companion of Sirius shone merely by reflected light from its primary, it would be much fainter than it is, and, indeed, would be utterly invisible in our largest telescopes. Further, in some double stars, spectroscopic observations suggest that the component stars have different spectra. This is, of course, conclusive evidence againt the hypothesis of borrowed light; for were the smaller star to shine by reflected light from the larger, the spectra of both would be identical, as in the case of the Sun and Moon. We may therefore conclude that all the visible stars are suns, and totally unfit for the habitation of living creatures.

But, may not the stars have planets revolving round them, forming solar systems similar to our own? As they are evidently suns shining by inherent light, may they not form centres of planetary systems? In the case of those stars having spectra differing from the solar spectrum, we cannot speak with any confidence; but for those which show spectra similar to that of our Sun, and having therefore, probably, a

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[1] *Journal of the British Astronomical Association*, March 1891.

similar chemical constitution, the existence of planets revolving round them seems, from analogy, very probable. I here refer to *single* stars, that is stars which have no telescopic close companion; for the double stars may, perhaps, form systems differently constituted. In any case these binary systems would not be strictly comparable with ours, for the Sun is certainly a single star.

Whether systems of planets really revolve round the stars referred to, is a question which, unfortunately, cannot be decided by observation. I have shown elsewhere[1] that if a planet equal in size to the "giant planet" Jupiter were revolving round the nearest star —α Centauri—at the same distance from that star that Jupiter is from the Sun, it would be utterly invisible in our largest telescopes. The invisibility of planets circling round the stars is therefore no proof whatever of their non-existence. Each star of the solar type may possibly be attended by a retinue of planets which may perhaps remain for ever invisible in the largest telescopes which man can construct. We can, therefore, draw our conclusions only from analogy. If other suns exist resembling our own Sun in chemical constitution, which we know to be a fact, is it not reasonable to suppose that they also form centres of planetary systems similar to the solar system?

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[1] *The Scenery of the Heavens*, p. 165.

Consult with reason, reason will reply,
Each lucid point which glows in yonder sky,
Informs a system in the boundless space,
And fills with glory its appointed place;
With beams unborrowed brighten other skies,
And worlds to the unknown with heat and light supplies.

The suns, which we call stars, were clearly not created for our benefit. They are of very little practical use to the Earth's inhabitants. They give us very little light; an additional small satellite—one considerably smaller than the Moon—would have been much more useful in this respect than the millions of stars revealed by the telescope. They must, therefore, have been formed for some other purpose.

On Laplace's Nebular Hypothesis, the condensation of an original nebulous mass endowed with a motion of rotation would result not only in the formation of a sun, similar to ours, but also in a system of planets revolving round the central body. If, indeed, the primitive nebula had no rotation or motions of any kind, the result would be a sun without planets or satellites; but the motions with which all the stars seem to be animated lead us to suppose that this would be a case of very rare occurrence. We may therefore conclude, with a high degree of probability, that the stars—at least those with spectra of the solar type—form centres of planetary systems somewhat similar to our own.

This being surmised, let us consider the conditions necessary for the existence of life on these planets.

There are various conditions which must be complied with before we can imagine life, as we know it, to be possible on any planet. Perhaps the most important of these is the question of temperature. We know that in the universe a great range of temperature exists, from the cold of interstellar space—estimated at about 460° below the freezing-point of water—to the intense heat which rages in the solar photosphere. In this long thermal scale life is, at least on the Earth, restricted within rather narrow limits. Below a certain low temperature life cannot exist. This point is, however, far above the temperature of space. On the other hand, above a certain high temperature—a low one, however, compared with the intense heat of the solar surface—life is also impossible, at least for highly organized beings, like man and the larger animals. For minute microscopic organisms the scale may, perhaps, be somewhat extended ; but even in its widest limits, the range of temperature within which life is possible is, so far as we know, certainly a narrow one.

For the support of life and vegetation, light is also necessary, for without no flowers would bloom, nor corn grow and ripen to maturity. To obtain this supply of light and heat it is necessary that a life-bearing planet should revolve at a suitable distance from, and in a nearly circular orbit round, a central sun. These conditions, it is hardly necessary to say, are fulfilled in the case of the Earth. Were we much nearer to the Sun than we are, we should suffer from excessive heat, and were we much further away, we should probably perish from cold. For this reason the existence of life on the other planets of the Solar System seems very doubtful. Mercury is probably too hot, and the other planets are certainly too cold, so far as heat from the Sun is concerned, unless, indeed, their internal heat is sufficient to raise the temperature of their surface to a point sufficient for the maintenance of life. Indeed, there is good reason to suppose that in the planets Jupiter, Saturn, Uranus, and Neptune, this internal heat is still so great that life would be quite impossible on their surface. Venus, inside the Earth's orbit, and Mars outside, are the two planets which seem to approach nearest to the required conditions. We know that both these planets possess atmospheres somewhat similar to ours, and, in Mars at least, land and water most probably exist on its surface. Venus is of course much hotter than the Earth, and Mars much colder, but possibly the polar regions of Venus, and the equatorial regions of Mars, may form suitable abodes for some forms, at least, of animal and vegetable life.

Let us proceed, however, to consider some other conditions necessary for the existence of life on a planet. A suitable temperature is, of course, indispensable, but this is not all. There are other conditions which must be complied with. The planet must have a rotation on its axis, so that every portion shall in turn receive its due share of light and heat. Each point on its surface must have its day and night, the day for work and the night for rest. The axis of rotation must not lie in the plane of the planet's orbit, but must have a suitable inclination, so that each hemisphere may enjoy its seasons, summer and winter, "seed-time and harvest," in due course. Further, the velocity of rotation on its axis must not be too rapid. If the Earth rotated in a period of one and a quarter hours, bodies at the equator would have no weight, and life would be impossible in those regions. The planet must also possess a mass sufficient to retain bodies on its surface by the force of gravity. In the case of very small bodies, such as the moons of Mars, and some of the minor planets between Mars and Jupiter, objects thrown into the air would pass away into space never to return. The planet should also have a mean density greater than that of water, otherwise the seas would possess no stability, and destructive waves would quickly destroy all life on its surface. All these conditions are fulfilled in the case of Mars as well as on the Earth. In the planet Saturn, however, the density is less than that of water, and in Uranus and Neptune only slightly greater.

The planet must also possess a suitable atmosphere. This is an all-important condition for the support of animal life—at least for the existence of man and the higher orders of animals. This atmosphere must consist—so far as we know—of oxygen and nitrogen gases mechanically mixed in proper proportions, and with a small quantity of carbonic acid gas. Were the oxygen in smaller quantity than it exists in the Earth's atmosphere, life could not be supported. On the other hand, were it much in excess of its present amount, a fever would be produced in the blood which would very soon put an end to animal life. The presence of other gases in excessive quantities would also render the air unfit for breathing. We see, therefore, that a comparatively slight change in the composition of a planet's atmosphere would—so far as our experience goes—render the planet uninhabitable by any of the higher forms of life with which we are familiar.

For the support of life on a planet, water is also absolutely necessary. Without this useful fluid the world would soon become a desert, and life and vegetation would speedily vanish from its surface.

Geological conditions must also be considered. It is clearly necessary for the welfare of human beings at least that the surface soil and rocks should contain coal, iron, lime, and other minerals, substances almost indispensable for the ordinary wants of civilized existence.

That all or any of the conditions considered would be complied with in the case of a planet revolving round a star, it is, of course, impossible to say. But when we find stars showing by their spectra that they contain chemical elements identical with those which exist in the Sun and the Earth, analogy would lead us to suppose that very possibly a planet resembling our earth may revolve round each of these distant suns. I say *a* planet, for evidently there would be only *one* distance from the central luminary—a distance depending on its size—at which the temperature necessary for the support of life would exist, as in the case of the Earth, over the *whole* of the planet's surface. For other planets of the stellar system, life would be, if it existed at all, most probably confined to restricted regions of the planet's surface. There would, therefore, be in each system one planet and only one, *especially* suitable for the support of animal life as we know it. This is with reference to light and heat. If the other conditions were not complied with, then life would probably not exist even on this one planet. In the case of a star larger than the Sun, the planet should be placed at a greater distance than the Earth is from the Sun, but in this case the length of the year and the seasons would be longer than ours.

The star which more nearly resembles the Sun in the character of the light which it emits is the bright star Capella. Arcturus has a somewhat similar spectrum. But these are probably suns of enormous size, if any reliance can be placed on the measures of their distance from the Earth. Other bright stars with spectra of the solar type are Pollux, Aldebaran, β Andromedæ, α Arietis, α Cassiopeiæ, α Cygni, and α Ursæ

Majoris. Another star is η Herculis. The magnitude of this star as measured with the photometer is about $3\frac{1}{2}$. A parallax found by Belopolsky and Wagner places it at a distance of 515,660 times the Sun's distance from the Earth. If the Sun were placed at this distance, I find that it would be reduced to a star of the third magnitude. This result would imply that η Herculis is a slightly smaller sun than ours; and a planet placed a little nearer to the star than the Earth is to the Sun might, perhaps, fulfil the conditions of a life-bearing world.

The number of stars visible in our largest telescopes is usually estimated at 100,000,000. Of these we may perhaps assume that 10,000,000 have a spectrum of the solar type, and therefore closely resemble our Sun in their chemical constitution. If we suppose that only one in ten of these is similar in size to the Sun, and has a habitable planet revolving round it, we have a total of 1,000,000 worlds in the *visible* universe fitted for the support of animal life.

We may therefore conclude, with a high degree of probability, that among the "multitudinous" stellar hosts there are probably many stars having life-bearing planets revolving round them.

IV.

THE RELATIVE BRIGHTNESS OF THE PLANETS.

THAT the planets shine with very different degrees of brightness is a fact familiar, perhaps, to most people. The great brilliancy of Venus, when favourably situated as a morning or evening star, is well known, and has frequently given rise to the erroneous idea that a new celestial visitor had appeared in the sky. Jupiter, when in opposition to the Sun and high in the heavens, as it is some years, also forms a brilliant object in our midnight sky, and it is closely rivalled in lustre by the "red planet" Mars when nearest to the Earth. The difficulty of detecting Mercury with the naked eye, owing to its proximity to the Sun, is well known. When seen, however, under favourable conditions, this planet shines with considerable brilliancy, but as it can only be seen at its brightest for a few days in the morning or evening sky a little before sunrise or a little after sunset, and then only for a comparatively few minutes in the twilight, it generally escapes the observation of the casual observer. The "ringed planet" Saturn usually appears brighter than an average star of the first magnitude, and may be easily distinguished by its dull yellow colour. The light of this planet is of course considerably increased when the ring system is widely open, the bright rings being very luminous; but when the rings are nearly invisible the brightness of Saturn is much reduced. Uranus is just visible to the naked eye on a clear night when its exact position with reference to neighbouring stars is known, but Neptune is quite beyond the range of unaided vision.

These differences in the relative brightness of the planets are due to four causes: (1) The distance of the planet from the Sun; (2) the distance of the planet from the Earth; (3) the size of the planet; and (4) the reflecting power of its surface, or the "albedo" as it is termed. Of these the first three are easily determined by observation, and a simple method of computing the relative albedos of the different planets forms the subject of the present paper.

The method of computation is as follows: The brightness of two planets will vary inversely as the square of their distance from the Sun, and *directly* as the size of the planet's disc as seen from the Earth, or, making due correction for their crescent and gibbous forms, as the square of their apparent diameters measured in seconds of arc. The results of this calculation will represent the relative brightness the two planets should have if both had the same albedo.

If, however, one of them appears brighter than calculation indicates, it implies that its reflecting power or albedo is greater than the albedo of the other. As the relative apparent brightness can be measured with a photometer, we have all the data necessary for calculation of the relative albedos.

The albedo is generally represented as a decimal fraction. This fraction denotes the proportion of light reflected compared with the amount received from the Sun; the albedo of a surface reflecting *all* the light which falls upon it would be represented by unity. Probably, however, no such surface exists, the albedo of even freshly fallen snow being less than unity.

The difference of albedo in the planets is in some cases very striking. In 1878, when Mercury and Venus were in the same field of view of the telescope, Nasmyth found that the surface of Venus was at least twice as bright as that of Mercury, although Mercury is nearer to the Sun. He compared Venus to clear silver, and Mercury to lead or zinc. From photometric observations by Pickering and Zöllner, the brightness of Venus is nearly as great as if its surface was covered with snow, and Zöllner found that the surface of Mercury is comparable with that of the Moon, which has a small albedo. This difference of surface brightness is very remarkable when we consider that Mercury is much nearer to the Sun than Venus. If we suppose that the surface of Venus is covered with a cloudy canopy, as has been suggested, this cloudy covering would perhaps account for the planet's great reflecting power, but the dullness of Mercury's surface is difficult to understand.

Owing to the uncertainty which exists as to the relative apparent brightness of Venus and Mercury, as viewed with the naked eye, it is not easy to compute correctly their relative albedos. Olbers found Venus, at its greatest brilliancy, 19 to 23 times as bright as Aldebaran, but Plummer estimated it as nine times brighter than Sirius, which would make it about 56 times brighter than Aldebaran. Mercury is perhaps about equal to Aldebaran when at its greatest brilliancy. I compared the planet and the star in June 1874, in India, and found them about equal.

Assuming that when Venus is at her greatest brightness, she is distant from the Sun 66,000,000 of miles, and that in this position she subtends an angle of 40″ of arc, and taking the corresponding quantities for Mercury as 28,000,000 and $8\frac{1}{2}''$ respectively, I find that Venus should appear about four times brighter than Mercury. Taking Venus as 20 times brighter than Aldebaran, we have the albedo of Venus equal to five times that of Mercury. Zöllner found for Mercury an albedo of 0·13. My calculation would therefore make the albedo of Venus equal to 0·13 × 5, or 0·65. Zöllner found 0·50. The data used in the above computation are, however, too uncertain to yield an accurate result.

For the planets outside the Earth's orbit, let us take Mars as our standard. For this planet, Zöllner found an albedo of 0·2672, or about double that of Mercury.

Comparing Mars and Jupiter, we have the mean distances from the Sun represented by the numbers 1·523 and 5·20. Their surfaces are therefore illuminated by sunlight in the inverse ratio of the squares of these numbers. That is, the solar illumination on Mars is to the solar illumination on Jupiter as the square of 5·20 to the square of 1·523, or as 27·04 to 2·32. The apparent diameter of Mars at mean opposition may be taken at 18″ of arc, and that of Jupiter at 46″. Hence the illuminated surface of Jupiter is $(\frac{46}{18})^2$ or 6·53 times that of Mars. The relative brightness of the two planets should therefore be $\frac{27 \cdot 04}{2 \cdot 32 \times 6 \cdot 53}$, or 1·78; that is, Mars should be 1·78 times brighter than Jupiter. Now Professor Pickering found the stellar magnitude of Jupiter, when in opposition, to be minus 2·52, or about 2½ magnitudes brighter than the zero of the scale of magnitudes, and that of Mars minus 2·25. This makes Jupiter 1·2823 times brighter than Mars. But we have seen that Mars should be 1·78 times brighter than Jupiter. Hence Jupiter is 1·78 × 1·2823, or 2·2825 times brighter than it should be had it the same albedo as Mars. The albedo of Jupiter must therefore be 0·2672 × 2·2825 = 0·609. Zöllner found an albedo of 0·62, but Bond computed that Jupiter emits more light than it receives from the Sun.[1] This would suggest that the planet shines with some inherent light of its own, a conclusion which has also been arrived at from other considerations.

In the case of Saturn, the existence of the bright rings complicates the observations of the planet's brightness. Pickering's photometric measures make it about equal to a star of the first magnitude when in opposition and the rings invisible. Mars is therefore 3·25 magnitudes, or about 20 times brighter than Saturn. Now the relative distances of Mars and Saturn from the Sun are represented by the numbers 1·523 and 9·539. The squares of these are 2·32 and 90·99, which implies that the intensity of the solar light on Mars is 39·2 times that on Saturn. Taking the apparent diameter of Mars at 18″, and that of Saturn at 19″, we have the apparent diameter surface of Mars $(\frac{18}{19})^2$ or $\frac{324}{361}$ that of Saturn. Mars should therefore be $39{\cdot}2 \times \frac{324}{361}$, or 35·17 times brighter than Saturn. But it is only 20 times brighter. Hence the albedo of Saturn must be greater than that of Mars in the ratio of 35·17 to 20, or the albedo of Saturn $= \frac{35{\cdot}17}{20} \times 0{\cdot}2672 = 0{\cdot}47$. Zöllner found 0·4981. I am inclined to think, however, from my own observations, that Saturn, when in opposition and shorn of his rings, is slightly brighter than a star of the first magnitude. If this be so, the albedo would have a somewhat higher value than that computed above.

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[1] Chambers' *Descriptive Astronomy*, 3rd edition, p. 117.

Coming now to the planet Uranus, we find the highest albedo of all the planets. Zöllner found 0·64, or slightly greater than that of Jupiter, but I find a still higher value. The relative distances of Mars and Uranus from the Sun are 1·523 and 19·183. The squares of these numbers are 2·32 and 367·99. Hence the intensity of the solar illumination on Mars is $\frac{367·99}{2·32}$, or 158·6 times that on Uranus. Taking the apparent diameter of Uranus at 4″, and that of Mars at 18″, as before, we have the area of the disc of Mars $(\frac{18}{4})^2$, or 20·25 times that of Uranus. Hence Mars should exceed Uranus in brightness 158·6 × 20·25, or 3211·65 times, if both planets had the same albedo. Now Zöllner found the stellar magnitude of Uranus to be 5·46; Pickering finds it 5·56, and my own eye observations make it about 5·4. We may therefore safely assume its brightness at 5·5 magnitude. This gives a difference of 7·75 stellar magnitude between Mars and Uranus, and implies that Mars is 1259 times brighter than Uranus. But we have seen that Mars should be 3211 times brighter, if the surfaces of the two planets had the same reflecting power. Hence it follows that the albedo of Uranus must be $\frac{3211·65}{1259}$, or 2·55 times greater than that of Mars. We have therefore the albedo of Uranus $= 0·2672 \times 2·55 = 0·68$, or nearly equal to that of white paper, which is 0·70.

Let us now consider the planet Neptune, for which

Zöllner found an albedo of 0·46. The relative distances of Mars and Neptune are 1·523 and 30·054. This gives the solar illumination on Mars 389·32 times that on Neptune. Taking their apparent diameters as 18″ and 2·9″ respectively, we have the result that Mars should be 14996·6 times brighter than Neptune. Now Pickering found the stellar magnitude of Neptune to be 7·96, which makes Mars 10·21 magnitudes, or 12,023 times brighter than Neptune. Hence we have the albedo of Neptune $= \frac{14996{\cdot}6}{12023} \times 0{\cdot}2672 = 0{\cdot}333$, a result in striking contrast to the albedo found above for Uranus. I think there can be no doubt that Uranus has the highest albedo of all the planets of the solar system. Comparing it with Jupiter, I find by the same method of computation that the albedo of Uranus is equal to the albedo of Jupiter multiplied by 1·213. Hence with Zöllner's value of Jupiter's albedo, 0·62, we have the albedo of Uranus 0·75, a very high value indeed, exceeding that of white paper, which is 0·70, and pointing strongly to the conclusion that Uranus is in a highly heated condition, a conclusion which seems to be partly supported by the evidence of the spectroscope.

To further test the high albedo of Uranus, let us compare the relative brightness of Uranus and Neptune. According to Professor Pickering's photometric measures, Uranus is 5·56 magnitude, and

Neptune 7·96. Uranus is therefore 2·4 magnitudes, or 9·12 times brighter than Neptune. The relative distances of the two planets from the Sun being 19·183 and 30·054, we have the intensity of the solar light on Uranus 2·4545 times that on Neptune. But the areas of the discs are as 4^2 to $(2{\cdot}9)$,^{2} or as 16 to 8·41. Hence the brightness of Uranus should be $\frac{16}{8{\cdot}41} \times 2{\cdot}4545$, or 4·67 times that of Neptune. Hence it follows that the albedo of Uranus must be $\frac{9{\cdot}12}{4{\cdot}67}$, or 1·9528 times that of Neptune. Assuming Zöllner's value of 0·46 for the albedo of Neptune, we have the albedo of Uranus = 0·46 × 1·9528 = 0·898 (!). Even with the low value of Neptune's albedo, which I have found above, viz. 0·333, the albedo of Uranus would be 0·333 × 1·9528 = 0·65, a value which still makes its albedo the highest of all the planets.

It is difficult to say what the albedo of the Earth itself may be. Possibly it does not differ much from that of the planet Mars. Professor Young gives it as perhaps 0·20. The Moon's albedo is rather low, 0·1736 according to Zöllner. It is, however, greater than that of Mercury, which seems to have the smallest reflecting power of all the planets.

With reference to the satellites, those of Mars are so small that we have no data for computing their albedos. Professor Pickering's estimates of their diameter were made on the assumption that their albedo is the same as that of Mars itself.

Assuming a diameter of 3400 miles for the third satellite of Jupiter, the largest and brightest of the system, and the mean diameter of Jupiter itself at 87,000 miles, we have the area of Jupiter's disc 655 times that of the satellite. If both have the same albedo, Jupiter should therefore be 655 times brighter than the satellite. Now Pickering finds the stellar magnitude of this satellite to be 5·24. This makes Jupiter 7·76 magnitudes, or 1271 times brighter than the satellite. Hence the albedo of Jupiter must be nearly twice that of the third satellite. This result agrees with the fact that dark spots have been observed on the third satellite by several astronomers.

The diameter of Saturn's largest satellite Titan is somewhat doubtful, but assuming it at 3000 miles, and its stellar magnitude to be 9·43, as measured by Pickering, the diameter of Saturn being 72,000 miles, I find that the albedo of Saturn would be 2·2 times that of Titan. This would make the albedo of Titan about 0·21, but owing to the uncertainty which exists as to its diameter, this result must be considered as somewhat doubtful.

The satellites of Uranus and Neptune are so faint that no satisfactory results could be computed. For the satellite of Neptune, Pickering finds a stellar magnitude of 13·82, or 5·93 magnitudes fainter than its primary. If we take the diameter of Neptune at 36,000 miles, and assume that its albedo is twice that of its satellite, I find that the diameter of the satellite would be about 3300 miles. Assuming the same albedo as Neptune, the diameter would be about 2340 miles.

V

A DOUBLE PLANET.

Double stars are numerous in the heavens, and double nebulæ are not uncommon. Even double comets have been recorded, as in the case of Biela's comet, and the faint companions which have been observed in close attendance upon some of the large comets of recent years. The duplicity of one of the satellites of Jupiter has even been "suspected," but, as far as I know, the suspicion has not been confirmed. Although many of the planets of the Solar System are attended by satellites, they are usually considered as single bodies. We may, however, perhaps, make an exception to this rule in the case of the Earth and Moon, which have been termed "a double planet" for the following reasons :—

The Moon's volume compared with that of its primary is greater than that of any other satellite of the Solar System. The volume is about $\frac{1}{49}$ of the Earth's volume, and its mass about $\frac{1}{81}$ of that of the Earth. The volumes of the satellites of the other planets bear a much smaller ratio to the volume of the primary. We need not consider the satellites of Mars, which are very minute bodies, and quite insignificant in size compared with their primary. The largest of the satellites of Jupiter has a volume only $\frac{1}{16000}$ of that of the "giant planet." The largest of Saturn's satellites, Titan, has probably not more than $\frac{1}{10000}$ of the volume of Saturn. The exact size of the satellites of Uranus is unknown, but judging from their faintness, we may conclude that their volume is small compared with that of their primary. Even the satellite of Neptune, supposed to be the largest satellite of the Solar System, is probably small compared with the planet. Taking its diameter at 3000 miles, and that of Neptune at 36,000 miles, the volume of the satellite will be only $\frac{1}{1728}$ of Neptune's volume.

We see, therefore, that the Moon is *comparatively* a very large satellite. It is, of course, *absolutely* smaller than the largest satellite of Jupiter, Saturn's satellite, Titan, or the satellite of Neptune; but compared with the Earth, which is a small planet (in comparison with Jupiter, Saturn, Uranus, or Neptune), it must be considered as really an enormous satellite, and in *relative* size deserving to rank rather as a small planet accompanying the Earth in its annual journey round the Sun, than as a satellite revolving round it.

Seen from Venus, the Earth and Moon will appear more like a "double planet" than a planet with an attendant satellite. From a consideration of the brightness of Venus as seen from the Earth, we may form an estimate of the probable brightness of the Earth and Moon as viewed from Venus. To do this it will, of course, be necessary to make some assumptions. We should require, in the first place, to know the albedo, or reflecting power, of the Earth's surface.

To determine this accurately would not be an easy matter, but if we assume that it has the same albedo as the Moon, we may not, perhaps, be very far from the truth. Now Zöllner found the albedo of Venus to be represented by the fraction 0·50, or about three times the Moon's albedo (0·1736).

Venus, when at her greatest brilliancy, and approaching inferior conjunction, is distant from the Earth about 39,000,000 miles, and has then about one-fourth of the area of her disc illuminated by sunlight. The Earth when in "opposition," and therefore at its brightest as seen from Venus, is distant from the planet about 26,000,000 miles. Hence we have the relative distances in the ratio of 39 to 26, or as 3 to 2.

If, to simplify the calculation, we assume the diameter of the Earth and Venus as equal, the apparent areas of their discs will be as 3^2 to 2^2, or as 9 to 4. That is, the area of the Earth's disc when in "opposition," as seen from Venus, will be about $2\frac{1}{4}$

times the area of Venus's disc when at her brightest as seen from the Earth. Now as the Earth shows a *full* face to Venus when at its brightest, and Venus only one-fourth of a fully illuminated disc when at its brightest to us, we should have the Earth brighter than Venus in the proportion of 36 to 4, or as 9 to 1, *if* the distances of both planets from the Sun and their albedos were the same. But as their distances from the Sun are in the ratio of 93 to 67, Venus will be more brilliantly illuminated in the ratio of 93^2 to 67^2, or about as 19 to 10, and as its albedo, as assumed above, is three times greater, we have the brightness of Venus's surface greater than that of the Earth's surface in the ratio of 57 to 10. Hence, finally, we have the brightness of the Earth, when in "opposition," as seen from Venus, brighter than Venus at its greatest brilliancy as seen from the Earth, in the ratio of 90 to 57.

Taking the diameters of the Earth and Moon as 7912 miles and 2163 miles respectively, the areas of their apparent discs would be in the ratio of 13·38 to 1. Hence, with the same albedo, the Earth and Moon, as seen from Venus, would differ in brightness by 2·81 stellar magnitudes.

Now Plummer found that Venus at its greatest brilliancy is nine times brighter than Sirius. The Earth, therefore, as seen from Venus, would appear $\left(\frac{90 \times 9}{57}\right)$ 14·21 times, or 2·88 stellar magnitudes brighter than Sirius. The Earth and Moon would therefore shine as two stars, one about half as bright again as Venus at her brightest, and the other about equal to Sirius, and separated, when the Moon is in "quadrature," by about $31'$ of arc, forming a superb "naked eye double star," perhaps the finest sight in the planetary system. They would present the appearance of a "double planet," in striking contrast with the faintness of the other satellites of the Solar System. The Earth would show a disc of about $62''$ in diameter, and the Moon one of about $17''$, and the markings on both might be well seen with a good telescope.

Seen from Mars, the Moon would also be visible as a small attendant planet to the Earth, but varying considerably in brilliancy owing to its phases.

The Moon's title to rank as a planet rather than a satellite is strengthened by the fact that her path in space is, like the planetary orbits, always concave to the Sun. Professor Young says, in his *General Astronomy*, that "if we represent the orbit of the Earth by a circle of 100 inches radius, the Moon would only move out and in a quarter of an inch, crossing the circumference 25 times in going once round it." This is a very different arrangement from the satellites of Jupiter and Saturn, which seem to form miniatures of the Solar System.

VI.

ALPHA CENTAURI AND THE DISTANCES OF THE STARS.

The saying of Seneca with reference to the impossibility of achieving immortality by ordinary efforts, that there is no easy way from the earth to the stars—*Non est ad astra mollis à terris via*—is one which may be applied in a literal sense to the determination of stellar distances. In old times, Hook, Flamsteed, and Cassini made numerous but unavailing efforts to measure the distance of some of the stars, and it is only in recent years that careful measurements made with accurate instruments have partially solved the enigma.

It was during a series of observations made by Sir William Herschel, at the close of the eighteenth century, carried out with a view to finding the distance of certain double stars, that he made his great discovery of binary or revolving suns. Although unsuccessful in his efforts to find the distance of the stars in question, his labours were fully rewarded by the discovery of stellar systems moving in obedience to the laws of universal gravitation. This important discovery—one of the most interesting of modern times—seems to have diverted his attention from his original design, but in any case his instruments were not sufficiently accurate for so delicate an investigation.

The bright southern star α Centauri is—so far as we know at present—certainly the nearest fixed star to the Earth. As might be expected from its comparative proximity to our system, it is one of the brightest stars in the sky. It ranks third in the order of brightness, Sirius being *facile princeps*, Canopus second, and α Centauri third. It is slightly brighter than Arcturus—which may perhaps be considered the leader of the Northern Hemisphere. The idea that this bright star might possibly lie within measurable distance was suggested by two facts. First, by its being a remarkable binary star, with the distance between the components unusually large for an object of this class; and secondly, from its large "proper motion" across the face of the sky, a fact which is usually assumed to indicate nearness to our system. An attempt to find its distance was made by Professor Henderson in the years 1832-33. Using a mural circle with a telescope of four inches aperture and a transit of five inches, he obtained an "absolute" parallax of 1·14″ of arc with a probable error of one-tenth of a second, indicating a distance from the Earth of about 181,000 times the

Sun's distance from the Earth. It may here be explained that the "parallax" of a fixed star is a change in the place of the star, due to the Earth's orbital revolution round the Sun. It is *one-half* the total displacement of the star as seen from opposite points of the Earth's orbit. In other words, it is the angle subtended at the star by the Sun's mean distance from the Earth, or the radius of the Earth's orbit. The "absolute" parallax is the actual parallax of the star. A "relative" parallax is the parallax with reference to a faint star situated near the brighter star, and which is assumed to lie at a much greater distance from the Earth. Sometimes the "relative parallax" comes out a negative quantity. This implies that the fainter or "comparison star" is nearer to the Earth than the brighter star.

Further measures of α Centauri made by Henderson and Maclear, in the years 1839 and 1840, with two mural circles of four inches and five inches, yielded an absolute parallax of 0·913 of a second, indicating a distance of about 226,000 times the Sun's distance from the Earth, or about 21 billions of miles. A re-discussion of these measures afterwards gave a parallax of 0·976 of a second. From observations in 1860-64, Moesta found with a transit circle of six inches aperture, a parallax of 0·88 of a second. From a new determination, the same astronomer found a smaller parallax of 0·521 of a second. Elkin and Maclear, in 1880, re-discussing Maclear's observations, found a parallax of 0·512 of a second. Dr. Gill, in 1881—1882, using a heliometer of $4\frac{1}{4}$ inches aperture, obtained a relative parallax of 0·76 of a second, with a probable error of only 0·013″. Elkin, using the same instrument in the years 1881—1883, obtained a relative parallax of 0·676 of a second. The difficulties attending the measures of an absolute parallax are so great that the relative parallaxes found for α Centauri are now considered the most trustworthy. Assuming that the small comparison stars used in determining the "relative" parallax are at such a distance that their parallax is inappreciable—as is probably the case—we may assume that the relative parallax is practically the same as the absolute parallax. Dr. Gill's result of 0·76″ for the parallax of α Centauri is now generally accepted as the most reliable. This places the star at a distance of 271,400 times the Sun's distance from the Earth, or about 25 billions of miles, a distance which light, with its great velocity of 186,300 miles per second, would take 4·287 years to traverse.

Taking the proper motion of α Centauri at 3·7″ of arc per annum, a parallax of 0·76″ would denote an annual motion of 4·868 times the Sun's distance from the Earth, or a velocity of about $14\frac{1}{3}$ miles per second in a direction at right angles to the line of sight. As there may also be—and probably is—a motion *in* the line of sight, either towards or away from the Earth, the star's actual velocity through space is probably greater.

As has been already mentioned, α Centauri is a remarkable binary or revolving double star. Its duplicity seems to have been first noticed by Richaud in 1690. Since the year 1752, numerous measures of the position of the components and the distance between them have been recorded, and many attempts have been made to compute the orbit. The apparent ellipse is a very elongated one, and the distance has varied from about 22″ to 1¾″. At present the distance is about 21″, so that the components may be seen with any small telescope. Unfortunately the star is not visible in these latitudes, but it must form a splendid telescopic object in the Southern Hemisphere. Various periods of revolution have been assigned to this magnificent pair of suns, ranging from 75⅓ to 88½ years. A recent investigation[1] by Dr. T. J. J. See of Chicago appears to definitely fix the period at 81·07 years. His results agree closely with those found by Dr. Gill,[2] and also with an orbit computed by Mr. A. W. Roberts,[3] and cannot be far from the truth. Assuming a parallax of 0·75″, Dr. See finds that the combined mass of the components is 1·998 times, or sensibly twice the mass of the Sun. He also finds

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[1] *Monthly Notices*, Royal Astronomical Society, December 1893.

[2] *Ibid.*, Royal Astronomical Society, vol. xlviii. p. 15.

[3] *Astronomische Nachrichten*, No. 3175.

that the longer axis of the real elliptical orbit is 23·592 times the Sun's distance from the Earth, or "about a mean between those of the planets *Uranus* and *Neptune;* but the orbit is so eccentric that in *Periastron* the two stars are only slightly remoter than the Sun and *Saturn* (11·3), while in *Apoastron* the distance considerably surpasses that of *Neptune* from the Sun (36·0)."

According to Dr. Gould there is a difference of 2½ magnitudes in brightness between the component stars of α Centauri. This makes the primary star ten times brighter than the companion. If we assume that both bodies have the same density and intrinsic brilliancy of surface, this ratio of brightness would imply that the mass of the larger star is about 31½ times the mass of the smaller.

The spectrum of α Centauri is, according to Professor Pickering, of the second or solar type, so we may perhaps conclude that it is a somewhat similar Sun to ours, the primary star having a mass nearly twice the mass of the Sun, and consequently a somewhat larger diameter.

Next in order of distance to α Centauri comes a small star numbered 21,185 in Lalande's catalogue, for which Winnecke found a parallax of about half a second of arc. The distance of this star is, however, not so certain as that of the famous star 61 Cygni, which is generally supposed to be the nearest star in the Northern Hemisphere. Although a comparatively insignificant star, of about the fifth magnitude, the attention of astronomers was attracted to it by its large "proper motion," about 5·2 seconds of arc per annum, a motion which places it fourth in the order of swiftly moving stars. Numerous measures of its distance have been made by various astronomers, from Arago and Mathieu in 1812, down to Professor Pritchard in 1886—1887. Most of these measures give a parallax ranging from about 0·27 to 0·56 of a second of arc. The mean of recent measures—which are of course the most reliable—may be taken at 0·45″, indicating a journey for light of about 7¼ years. This parallax combined with the star's proper motion of 5·2″ indicates a velocity of 34 miles a second, at right angles to the line of sight.

Like α Centauri, 61 Cygni is a wide double star, both components apparently moving together through space. This fact evidently points to a physical connection between the two stars, and suggests that one revolves round the other, or rather both round their common centre of gravity. Several attempts have been made to determine an orbit, but as the angular motion since their discovery has not been considerable, there is still a doubt as to the binary character of the pair. If they are really revolving, the period of revolution must be measured by hundreds of years. Assuming a period of 782½ years found by Peters, I find that the combined mass of the components would be 0·461 of the Sun's mass, with a mean distance between them of 65·62 times the Sun's mean distance from the Earth. This result may not be very far from the truth, for I find that the Sun placed at the distance of 61 Cygni would shine as a star of about 2·8 magnitude.[1] Now, taking the magnitude of 61 Cygni at 4·98—as measured with the wedge photometer at Oxford—we have a difference of 2·18 magnitudes, which implies that the Sun is about 7½ times brighter than the combined light of the components of 61 Cygni, and its mass, therefore, probably considerably greater.

Next in order of distance to 61 Cygni comes the brilliant Sirius. Details respecting the distance and probable size of this star will be found in the article on 'Sirius and its System' in the present volume.

For the third magnitude star η Herculis, Belopolsky and Wagner found a parallax of 0·40 of a second, or about the same as that of Sirius, but so far as I know this result has not been confirmed by any other astronomer.

For the binary star η Cassiopeiæ, Schweizer and Socoloff found a parallax of 0·3743 of a second. With this parallax, and assuming a period of 222 years found by Dr. Doberck, I find the mass of the system only 0·366 of the Sun's mass. Placed at the distance of η Cassiopeiæ, the Sun would, I find, be reduced to a star of 3·2 magnitude, or slightly brighter than the

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[1] See chapter on 'The Sun among his Peers.'

star appears to us. As the spectrum of η Cassiopeiæ is of the second or solar type, the two bodies may, perhaps, be comparable in physical constitution, and a comparison of their relative brightness agrees fairly well with their relative mass.

There are some other stars with fairly well determined parallaxes of $\frac{1}{6}$ to $\frac{1}{3}$ of a second of arc, but those referred to above are the most remarkable.

That α Centauri and the other stars we have been considering are comparatively near neighbours of our system may be seen from the fact that Dr. Elkin finds an average parallax of only 0·089 of a second for stars of the first magnitude. This gives an average distance of 8½ times the distance of α Centauri, and implies that an average star of the first magnitude is about 72 times brighter than a first magnitude star placed at the distance of α Centauri. Our nearest neighbour is, however, about twice as bright as an average star of the first magnitude. It follows, therefore, that, on the average, stars of the first magnitude are really some 36 times brighter than α Centauri. If of the same intrinsic brilliancy of surface, this result would indicate that stars of the first magnitude are suns about six times the diameter of α Centauri, and, therefore, much larger in volume than that star and our Sun.

The theory that the stars may be assumed to be, generally speaking, of nearly equal size and brightness, an hypothesis advocated by Sir William Herschel and the elder Struve, is now shown to be erroneous by the fact that comparatively faint stars like 61 Cygni and Lalande 21,185 are at a measurable distance from the Earth, while the bright southern star Canopus—second only to Sirius in brilliancy—is at such a distance that a small parallax of only 0·03 of a second, found by Dr. Elkin, seems of very doubtful value. If the result found by Dr. Elkin for the average parallax of stars of the first magnitude is correct, we are led to the conclusion that the brightest stars in the heavens—with the exception of Sirius and α Centauri, and perhaps Procyon—owe their brightness to enormous size, and not to comparative proximity to our system.

The distances of two stars from the Earth being known, it is easy to calculate the distance between them in space. For, knowing the exact position of each star on the celestial vault, we can compute the angular distance between them. We have then two sides of a triangle and the included angle, and we can, therefore, calculate by trigonometry, or by a simple graphical construction, the length of the third side, which is the required distance between the stars. Taking Sirius and α Centauri, I find that the angular distance between them is 88½ degrees. Now, taking the parallax of α Centauri at 0·76″, and that of Sirius at 0·39″, I find that the distance between the two stars is about 589,000 times the Sun's distance from the Earth. This corresponds to a parallax of 0·35

It follows, therefore that Sirius seen from *α* Centauri would appear nearly as bright as we see it; while *α* Centauri viewed from Sirius would be diminished in brilliancy, and probably reduced to nearly a star of the second magnitude.

VII.

THE SUN AMONG HIS PEERS.

THE Sun is a star, and the stars are suns. This fact has been a familiar one to astronomers for many years, and is probably known to most of my readers. That the stars shine by their own inherent light, and not by light reflected from another body, like the planets of the Solar System, may be easily proved. That many of them at least are very similar to our own Sun is clearly shown by several considerations. I will mention three facts which prove this conclusively. First, their great intrinsic brilliancy compared with their small apparent diameter, a diameter so small that the highest powers of the largest telescopes fail to show them as anything but mere points of light without measurable magnitude. Second, their vast distance from the Earth, a distance so great that the diameter of the Earth's orbit dwindles almost to a point in comparison. This accounts satisfactorily for the first fact. Third, the spectroscope—that unerring instrument of modern scientific research—shows that the light emitted by many of them is very similar to that radiated by the Sun. Their chemical and physical constitution is, therefore, probably analogous to that of our central luminary. The red stars certainly show spectra differing considerably from the solar spectrum, but these objects are comparatively rare, and may perhaps be considered as forming exceptions to the general rule.

The stellar spectra have been divided into four types or classes. The first class includes stars like Sirius, in which the strong development of the hydrogen lines seems to indicate the preponderance of this gaseous metal in the glowing envelopes of these distant suns. The second class includes stars in which the spectrum closely resembles the solar spectrum. The third and fourth types include those which show a banded spectrum, the rainbow-tinted streak of ordinary stellar spectra being crossed by a number of dark bands or shadings, in striking contrast to the solar spectrum, in which fine lines only are visible. These are mostly of an orange or red colour of various degrees of intensity, and many of them are variable in their light. There is some reason to suppose that stars of the first type are probably the hottest and intrinsically the brightest of all, and are not, therefore, fairly comparable with our Sun. In considering, therefore, the Sun's rank in size and brightness among the stellar hosts, we should compare it with those which show a similar spectrum.

But how are we to compare the Sun with any star?

It is clear that the first thing we require to know is the star's distance from the Earth. The apparent size and brightness of an object depends on its distance from the eye. A candle placed a few feet from us will look larger and give more light than a brilliant electric lamp several miles away. Venus is, at its brightest, considerably brighter than Jupiter, although the former is a much smaller planet than the latter. Unfortunately the distance of but few of the fixed stars from the Earth has been ascertained with any approach to accuracy. Failure in the attempt to measure the distance of a star implies, of course, that it lies at a vast distance from the Earth. In several cases, however, the efforts of astronomers have been rewarded with success, although the result found for some stars is still open to much uncertainty. In addition to their distance, we also require to know the *apparent* brightness of the Sun with reference to the star with which it is to be compared. Owing to the excessive brilliancy of the Sun compared with even the brightest stars, this is a matter of no small difficulty. Photometric measures, made with the aid of the Moon as a "medium," have however yielded a fairly reliable result, and it is now generally assumed by astronomers that on the scale of stellar magnitudes which represents the brightest stars as of the first magnitude, and those near the limit of ordinary eyesight as sixth magnitude, the Sun's light may be expressed as about 26½ magnitudes brighter than an average star of the first magnitude, such as Altair or Spica. This may seem to some a rather surprising result. It may be asked, if there is a difference of five magnitudes between a sixth magnitude star and one of the first magnitude, should not the difference between a first magnitude star and the Sun be much more than 26½ magnitudes? At first sight, the number representing the Sun's stellar magnitude certainly does seem small, but a little consideration will soon dispel this feeling of surprise. The explanation of the apparent difficulty is a simple one and will be easily understood by those familiar with the rules of arithmetic. The numbers denoting star magnitudes really form a geometrical series. Thus a star of the fifth magnitude is about two and a half (more correctly 2·512) times brighter than a star of the sixth magnitude; a star of the fourth two and a half times brighter than one of the fifth, and so on. This series increases very rapidly, like the question of the nails in a horse's shoes in books on arithmetic. With the "ratio" of 2·512, a star of the first magnitude would be one hundred times brighter than one of the sixth. A difference of ten magnitudes between two stars would denote that one is 10,000 times brighter than the other; and if we go on to 26½ magnitudes above the first magnitude we arrive at a very large number indeed. In fact, the number 26½ implies that the Sun is equal in brightness to 39,811,000,000, or nearly 40,000,000,000 of stars of the first magnitude, like Altair or Spica.

Knowing, then, the Sun's stellar magnitude, we can easily calculate what its apparent brightness would be if placed at the distance of a star of which the distance from the Earth has been determined. For, as light varies inversely as the square of the distance, we have simply to express the distance of the star in terms of the Sun's distance from the Earth, square this number, and then find how many stellar magnitudes would give the diminution of light indicated by the number thus obtained. A "parallax" of one second of arc would represent a stellar distance of 206,265 times the Sun's mean distance from the Earth. At this distance the Sun would shine as an average star of the first magnitude. If the star's parallax is only a fraction of a second—as it always is—we have to divide 206,265 by the parallax to obtain the distance sought. For example, the most reliable measures give a parallax for Sirius of about four-tenths of a second of arc. Dividing this into 206,265, we have the distance of Sirius equal to 515,662 times the Sun's distance from the Earth. I find that the square of this number represents a diminution of light of 28½ stellar magnitudes. Subtracting 26½ from this, we have the result that the Sun's light would be reduced to two magnitudes below the first, or to the third magnitude, if it were placed at the distance of Sirius. In other words, Sirius, which is about two magnitudes brighter than an average first magnitude star, is four stellar magnitudes, or about forty times brighter than the Sun would be in the same position as seen from the Earth.

From observations of a faint companion which revolves round Sirius in a period of about 58 years, I find that the combined mass of this brilliant star—the brightest of the stellar hosts—and its companion, is about three times the mass of the Sun. Now, if Sirius were of the same intrinsic brightness as the Sun, and of the same density, its diameter would be 6·32 (the square root of 40) times the Sun's diameter, and its mass would be 6·32 cubed, or 253 times the mass of the Sun. We see, then, that Sirius is enormously bright in proportion to its mass, or in other words, that it is a much less massive star than its great brilliancy would lead us to imagine. It must therefore differ considerably in its physical constitution from that of our Sun. Other stars of the same class are probably comparable with Sirius in the exceptional brilliancy of their luminous surface. Stars of the first type are, therefore, of probably small mass in proportion to their brightness, and cannot be fairly compared with the Sun in size, or at least in the quantity of matter they contain. Professor Pickering finds that the brightest stars of the Milky Way belong to the Sirian type, and Dr. Gill concludes, from an examination of Galactic photographs, that the smaller stars composing the Milky Way are for the most part blue stars, and have probably spectra of the Sirian type. If this be so, they are probably really as well as apparently small, a conclusion which had been previously arrived at from other considerations.

Let us now consider stars of the second or solar type. Among the brighter stars of this class we have Capella, Arcturus, Aldebaran, Pollux, *α* Cygni, *α* Arietis, *α* Cassiopeiæ, etc., in the Northern Hemisphere, and Canopus and *α* Centauri in the Southern.

For Capella, which rivals in brightness Arcturus and Vega (and forms with them the most brilliant trio in the Northern Hemisphere), Dr. Elkin finds a parallax of only slightly more than one-tenth of a second of arc. At the distance indicated by this result—nearly 2,000,000 times the Sun's distance from the Earth—the Sun would shine as a star of only the sixth magnitude. This implies that Capella is about 250 times brighter than the Sun. If of the same intrinsic brilliancy of surface, its diameter would, therefore, be about sixteen times the Sun's diameter, or nearly fourteen millions of miles! As the spectrum of Capella is almost identical with the solar spectrum, it seems probable that the physical constitution of the Sun and star are similar. We must, therefore, if its measured distance be reliable, consider Capella to be a vastly larger body than our Sun. The above diameter would imply a volume equal to 4000 suns, a truly stupendous globe!

A minute parallax of about one-sixtieth of a second of arc, found for Arcturus by Dr. Elkin, gives a still more astounding result. This small parallax implies a distance from the Earth equal to about twelve million times the Sun's distance. This vast distance would produce a diminution of light of about 35¼ magnitudes, so that the Sun placed at the distance of Arcturus would be reduced to a star of only 9¾ magnitude! It would not be visible with an opera glass! Arcturus is, therefore, in round numbers 9½ magnitudes, or over 6000 times brighter than the Sun would be at the same distance. Assuming the same density and brightness of surface as the Sun, the diameter of Arcturus would, therefore, be about 79 times the Sun's diameter, or over 68,000,000 miles, and its mass about 500,000 times the mass of the Sun; figures well calculated to "stagger the imagination." From the small value of the parallax found for Arcturus, we cannot, of course, place very much reliance on its accuracy; but there can be little doubt that the distance of this bright star is really very great, and that consequently it is a much larger sun than ours, probably one of the most massive bodies in the universe.

A mean of the results found by Elkin and Hall for Aldebaran would reduce the Sun to a star of nearly the sixth magnitude at the same distance, and its light would fade to a star of below the eighth magnitude if it were removed to the distance found by Professor Pritchard for α Cassiopeiæ.

For the bright star Pollux, Dr. Elkin found a parallax of only 0·068 of a second, representing a distance at which the Sun would be reduced to a star of about the seventh magnitude. This makes Pollux 164 times brighter than the Sun, indicating a diameter about thirteen times greater, or about 11,000,000 miles!

Dr. Elkin's result for the bright southern star Canopus would give the Sun a magnitude of only 8½ if placed at the same distance. As this brilliant star —second only to Sirius in lustre—is nearly one magnitude brighter than Arcturus, we see that it is probably comparable with the Northern star in size.

A negative parallax found by Elkin, Glasenapp, and Peters for α Cygni, and a similar result arrived at by Downing and Main for γ Draconis, indicates, of course, that these stars lie at a vast distance from the Earth, a distance, perhaps, too great for our present methods of measurement. Their comparative brilliancy, especially that of α Cygni, would, therefore, suggest that they are very massive bodies, far exceeding our Sun in absolute size.

The results I have given will show that the brilliancy of some at least of the brighter stars may probably be explained by their enormous size in comparison with the Sun. Placed at the same distance from the Earth, the Sun would dwindle to an insignificant star, invisible in some cases to the naked eye!

For some stars of the solar class, however, smaller distances have been found. For η Herculis, a star of about 3½ magnitude, Belopolsky and Wagner found a parallax of four-tenths of a second, indicating a distance about the same as that of Sirius. As at this distance the Sun would be only reduced to the third magnitude, it would seem that we have here a star of rather smaller mass than our Sun.

In the case of binary or revolving double stars, if we can determine their distance we can easily calculate the combined mass of the components in terms of the Sun's mass. Assuming the most reliable distance and the best orbits computed for the following binary stars—η Cassiopeiæ, 40 Eridani, Sirius, Castor, α Centauri, 70 Ophiuchi and 61 Cygni—I find the total mass of these seven stellar systems equal to 14½ times the mass of the Sun, or an average of twice the Sun's mass for each system. Omitting Sirius and Castor, which have spectra of the first type, the others being of the second, we have a total mass of five systems of 11½ times the mass of the Sun, or an average of 2·31 for each system. Here we have five suns or rather five pairs of suns, not differing greatly from our own Sun in mass. Indeed one of them, 61 Cygni, is of smaller mass, if the orbit computed by Peters can be relied upon. There seems, however, to be still some doubt as to whether this famous pair really forms a binary system. Its distance from the Earth has, however, been satisfactorily determined by several astronomers. The later results are fairly accordant, and it may be confidently assumed that its parallax is about 0·45 of a second of arc, representing a distance of 458,366 times the Sun's distance from the Earth. At this distance I find that the Sun would be reduced to a star of about 2·8 magnitude. Now from the photometric measures made at Oxford, the stellar magnitude of 61 Cygni is 4·98. The difference, or 2·18 magnitudes, implies that the Sun is about 7½ times brighter than the combined light of the components of 61 Cygni, and its mass, therefore, probably greater.

At the distance of α Centauri—the nearest of all the fixed stars—the Sun would be reduced to 1·7 magnitude, or about one magnitude fainter than the star appears to us. This would indicate that, if of the same brightness and density, the mass of the system of α Centauri is about four times the mass of the Sun. A calculation based on the computed orbit gives a mass about twice that of the Sun, a not very discordant result, as, according to Professor Pickering, there is something "peculiar" about the star's spectrum which may imply that its density and intrinsic brightness are perhaps somewhat different from that of the Sun.

Compared, however, with some faint stars which show a relative proximity to our system, the Sun will contrast very favourably in size, or at least in brightness. A star of about the seventh magnitude in the constellation Ursa Major, numbered 21,185 in Lalande's catalogue, has been found by Winnecke to have a parallax of about half a second of arc. At the distance indicated by this comparatively large parallax the Sun would shine as a star of about 2½ magnitude, which would make it about fifty times brighter than Lalande's star. Another small star in the same constellation, number 21,258 of Lalande's catalogue, although of only 8½ magnitude, yielded to Auwers a parallax of 0·262 of a second, which may be considered as a comparatively large one. At the distance indicated, the Sun would be reduced to a fourth magnitude star, denoting that its brilliancy is about 63 times greater than Lalande's star.

Two small stars of the ninth magnitude, numbered 11,677 and 17,415 in the catalogue of Œltzen and Argelander, have been found to show a similar distance, the Sun being reduced to about the fourth magnitude in both cases. Here we have a difference of five magnitudes, which implies that the Sun is a hundred times brighter than these faint, although comparatively near stars.

We may therefore conclude that while some of the brighter stars are probably vastly larger than our Sun, others are almost certainly much smaller. The larger stars, overcoming as they do the dwindling effect of vast distance by their stupendous size, may possibly form exceptions to the general rule of stellar mass, and those faint stars which are at a measurable distance from the Earth, showing by their feeble light and comparative proximity that they are really as well as apparently small, may also form exceptions in the opposite direction.

The conclusion then seems probable that the Sun is an average-sized star, neither an exceptionally large nor an exceptionally small member of the vast and varied sidereal system which forms our visible universe.

VIII.

REVOLVING SUNS.

SOME stars seen with the naked eye seem very close together. These, although not regarded by astronomers as double stars, very much resemble real double stars as seen in a telescope. Of these "naked eye doubles" may be mentioned Mizar and Alcor, α Capriconi, θ Tauri (in the Hyades), o Cygni, etc. But the distance which separates even the closest of these is very considerable when compared with the objects revealed by the telescope. And even among those included in double star catalogues, the distance varies considerably, from doubles which can be easily seen with telescopes of two or three inches in diameter, to those excessively close objects which require the highest powers of the largest telescopes to show them as anything but single stars.

The term "double" star seems to have been first used by Ptolemy, who applied the Greek word *diplons* or "double" to ν Sagittarii, which consists of two stars of the fifth magnitude close together, as seen with the naked eye.

The first double star discovered with the telescope seems to have been θ Orionis—the middle star of the "sword"—in which Huygens is said to have seen four stars in 1656, and γ Arietis— the faintest of the three well-known stars in the "head of Aries"—which was first seen double by Hooke in 1664, while observing the comet of that year. "I took notice," he says, "that it consisted of two small stars very near together; a like instance of which I have not else met with in all the heavens." This is an excellent object for a small telescope, as the components are nearly equal, and separated by nearly 8″ of arc. The duplicity of α Centauri is said to have been discovered by Richaud in 1690. Bradley divided γ Virginis in 1718, and Castor in the same year.

The appearance of these double stars naturally suggests the idea that they are comparatively close together, and at about the same distance from the Earth. It is of course possible that one of the stars might lie far beyond the other in space, thus forming what is called an "optical double." This may probably be the case when one is much brighter than the other, and the apparent distance between them is considerable. But in those double stars of which the components are nearly equal and very close, it seems more probable that they lie at nearly the same distance from the Earth. In a paper read before the Royal Society in the year 1767, by the Rev. John Michell, he showed that the mathematical probability of even the two stars of β Capricorni being merely placed together by the effect of chance was only $\frac{1}{80}$, or in other words the odds were 80 to 1 against the accidental proximity of these two stars. The chances against accidental arrangement are of course much increased in the case of telescopic doubles. For example, the bright star Castor consists of two nearly equal stars separated by a distance less than $\frac{1}{30}$th of that which divides the components of β Capricorni, and there are of course many doubles very much closer than Castor. In the case of three or more stars lying close together, the chances are of course still further increased. In the case of the Pleiades, Michell found that the odds were no less than 500,000 to 1 against the accidental grouping of the six brightest stars of this famous cluster. Now that photography has shown that the Pleiades contain over 2000 stars, the probability rises to an absolute certainty that they are physically connected.

From these considerations Michell concluded that in all probability many of the double stars form systems connected by the laws of universal gravitation. He did not, however, put this very plausible hypothesis to the test of observation, and it was reserved for Sir William Herschel to discover—towards the close of the eighteenth century—the actual existence of revolving stars. It does not appear, however, that Herschel was acting on Michell's suggestion when he made the discovery with which his name is usually associated, and to Michell seems clearly due the discovery from abstract reasoning of the probable existence of these stellar systems. Herschel's observations were made with a view to determine the distance of certain double stars from the Earth. Supposing one of the stars to be much nearer to the Earth than the other, there would result an annual swaying to and fro of the components, due to the Earth's revolution round the Sun. Instead of this apparent annual motion, Herschel found, after twenty-five years of observation, that in many cases there was a progressive motion of one of the components constantly in the *same* direction, thus indicating that the stars were actually revolving round each other. Here was a remarkable discovery, one of the most wonderful of modern times—the existence of revolving suns. As Herschel himself expressed it, "he went out, like Saul, to seek his father's asses, and he found a kingdom." For some twenty years after Herschel's interesting discovery—announced in 1803—little seems to have been done in the observation of double stars. This apparent neglect was principally due to the fact that telescopes sufficiently powerful to deal satisfactorily with the closer double stars had not yet been constructed. The work was however soon taken up by Sir John Herschel in England and Struve in Russia, and these famous astronomers added greatly to our knowledge of the subject.

Between the years 1830 and 1868, valuable work was done in this interesting branch of astronomical research by Dawes, Dembowski, Jacob, Mädler, Powell, Secchi, Smyth, and others; and in more recent years by Burnham, Doberck, Englemann, Glasenapp, Schiaparelli, Tarrant, etc. The number of known double stars has been largely increased by the labours of Mr. Burnham, who has discovered over 1000 pairs, most of them very close, and many of them certainly in orbital motion.

The first attempt at calculating the orbit of a binary, or revolving double star, was made by Savary in the year 1830. The star selected was ξ Ursæ Majoris. This remarkable pair of suns was discovered by Sir William Herschel in 1780. Savary found a period of revolution of 58¼ years, but a slightly longer period of 60¾, computed by Dunér in 1876, is probably nearer the truth. The companion star has therefore made one complete revolution round its primary since its discovery, and is now far advanced in a second revolution. Although the components are not at present at their greatest distance apart, they are yet within the range of telescopes of moderate size.[1]

The next binary star which seems to have been attacked by the astronomical computer was 70 Ophiuchi, for which Encke computed, in 1830, a

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[1] A diagram of the orbit of this remarkable pair will be found in *Knowledge* for August 1890.

period of 79 years, and Sir John Herschel, in 1833, 80 years. Recent calculations, however, make the period somewhat longer, an orbit computed by the present writer in 1888 giving a period of about 88 years. An orbit by Mr. Mann, published in 1890, also makes the period 88 years, a period also found by Mr. Burnham in 1893. More than a complete revolution has been performed since its discovery by Sir William Herschel in 1779. An orbit for the famous pair γ Virginis was computed by Sir John Herschel in 1833. He found periods of 513 and 629 years, but more recent calculations have reduced this period to about 180 years. In the year 1836 the distance between the components of this remarkable pair became so small that only the largest telescopes could show any sign of the star being double. The stars have now opened out again, and are at present visible with even a small telescope. 'The Story of Gamma Virginis' has been well told by Admiral Smyth in his admirable *Celestial Cycle* (vol. ii.), and forms a most interesting chapter in the history of astronomy.

An orbit for Castor was next computed by Sir John Herschel, in 1833. He made the period about 252½ years, but recent calculations appear to indicate a much longer period.

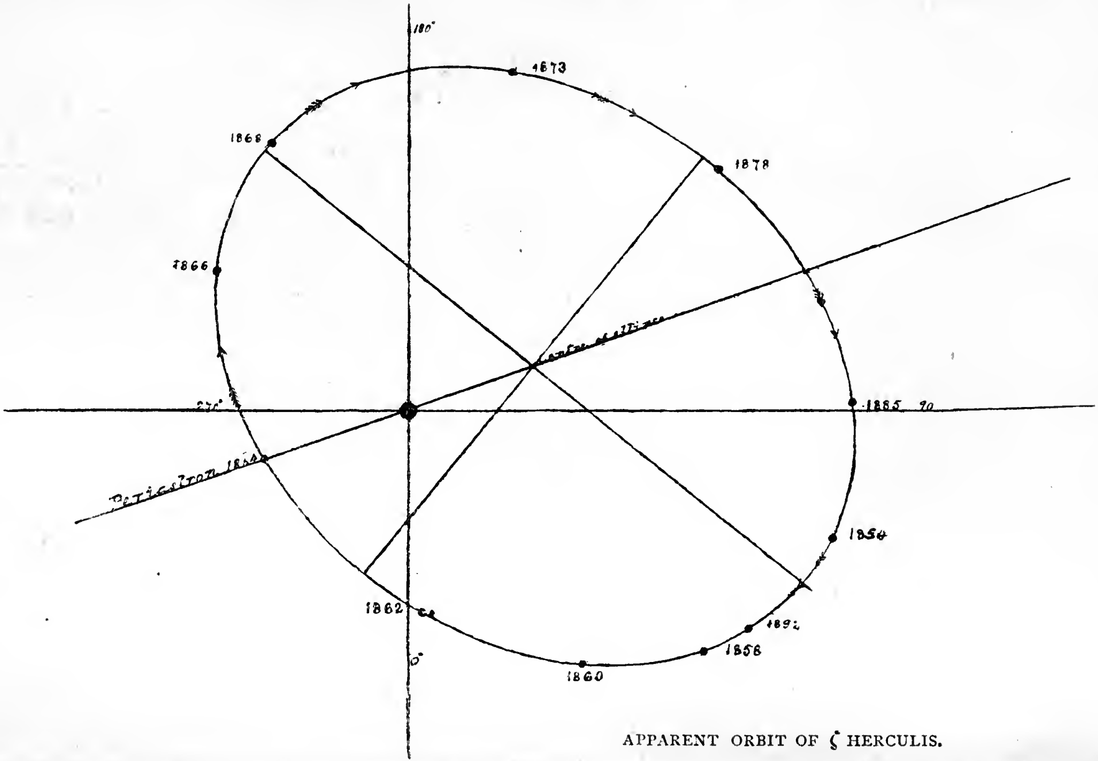
Orbits were also computed in 1833 by Sir John Herschel for ξ Ursæ Majoris, ξ Boötis, and η and σ Coronæ Borealis. These were followed by ζ Herculis in 1839, ω Leonis 1841, and ζ Cancri and Struve 3062 in 1842, for which orbits were computed by Mädler. Since 1842, numerous orbits have been computed by Doberck, Mädler, Hind, Glasenapp, the present writer, and others; and the orbits of about 80 different binary stars have now been calculated.

The periods of revolution of the computed orbits vary in length from about 11½ to 1625 years (ζ Aquarii). The great length of the longest period renders its accuracy of course doubtful, and many years must elapse before a satisfactory orbit can be computed for such a slow-moving star. The orbits of some of those with shorter periods are, however, known with considerable accuracy.

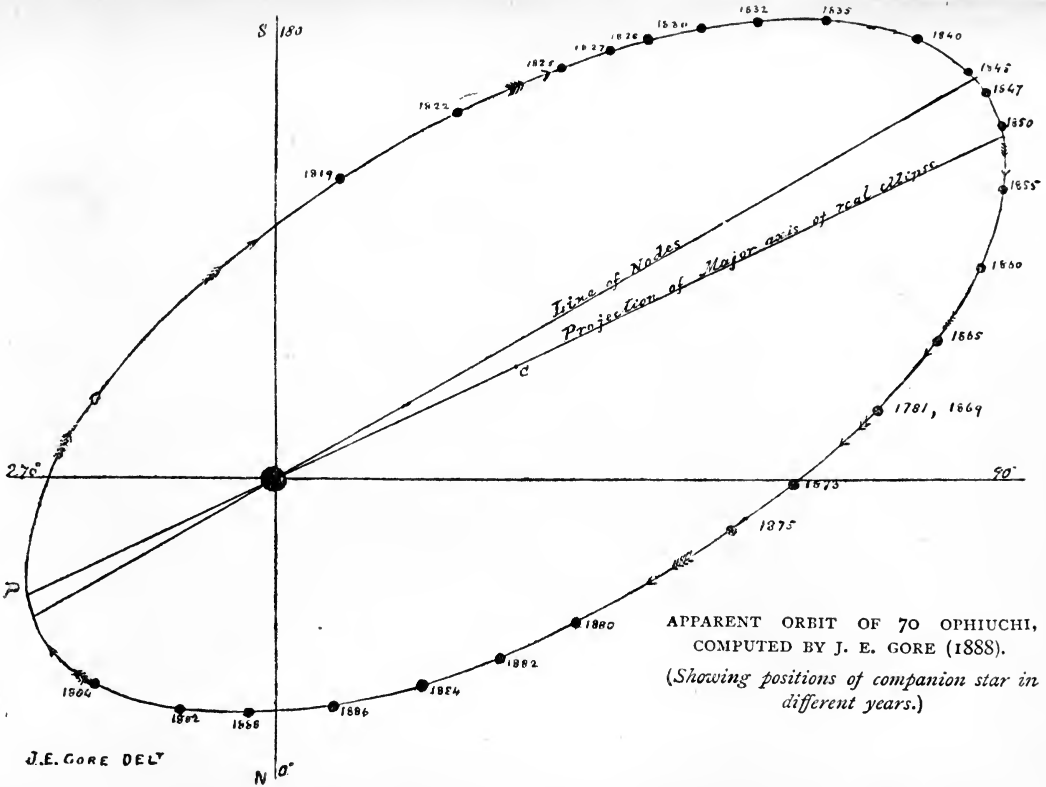
The shortest period yet computed for any binary star—at least for those visible with a telescope—is that of δ Equuleii, for which the Russian computer Wrublewsky finds 11½ years. Owing, however, to the closeness of the components, and the consequent difficulty of making accurate measures even with large telescopes, the orbit does not represent the observations very satisfactorily. Burnham found only a "slight elongation" of the star with the great telescope of the Lick Observatory in July 1889!

The distance between the components does not at any time exceed half a second of arc, so that it is always beyond the reach of all but the largest telescopes.

Another star which has a period of between 11 and



APPARENT ORBIT OF ζ HERCULIS.



APPARENT ORBIT OF 70 OPHIUCHI, COMPUTED BY J. E. GORE (1888).

(Showing positions of companion star in different years.)

12 years is κ Pegasi, for which an orbit has recently been computed by Professor Glasenapp. The bright southern star ζ Sagittarii is also a rapid binary. An orbit computed by the present writer in 1886 makes the period about 19 years. 85 Pegasi has a period of about 22 years; 42 Comæ Berenices about 26 years; β Delphini under 30 years; ζ Herculis about 34½ years (three complete revolutions have been performed since its discovery by Sir William Herschel in 1782); and there are about 21 binaries with periods of less than 100 years.

The bright southern star α Centauri—the nearest of all the fixed stars to the Earth—is also a remarkable binary, with a period of 81 years.

Of those with periods of over 100 years, the following are the most remarkable and interesting:—

ω Leonis.—This star, which is about 5½ magnitude, lies a few degrees preceding ο Leonis (fourth magnitude). The companion, which is about the seventh magnitude, has nearly completed one revolution since its discovery by Sir William Herschel in 1781. Dr. Doberck's period of 114½ years is probably the best.

ξ Boötis.—An interesting binary discovered by Sir W. Herschel in 1780. Dr. Doberck's period of 127 years is perhaps the best. The distance between the components is at present diminishing, but it is still within the reach of small telescopes.

η Cassiopeiæ.—This well-known double star, of which the components are of magnitudes 4 and 7½, has described a considerable portion of its orbit since its discovery by Sir W. Herschel in 1779, the distance diminishing from about 11″ to 4¾″. Dr. Doberck's period of 222½ years is perhaps the best hitherto computed. This is also within the power of small telescopes. The colours of the components are, according to Webb, yellow and garnet.

44 (i) Boötis.—For this binary star, Mädler found a period of 181 years, and Doberck 261; the longer is probably nearer the truth. The plane of the orbit is highly inclined to the background of the sky, and lies, I find, at right angles to the general plane of the Milky Way, a position which I have also found to exist in other binary systems. The magnitudes of the components are about 5 and 6, and the pair may be seen with small telescopes.

δ Cygni.—This bright star has a faint companion of the eighth magnitude, which is in orbital motion round the primary. Behrmann found a period of 415 years. An orbit recently computed by the present writer makes the period about 376½ years, but of course many years must elapse before a really accurate orbit can be computed.

12 Lyncis.—This is a triple star, the components being about 5, 6 and 7½ magnitudes. The close pair forms a binary system, and an orbit computed by the present writer gives a period of about 486 years. Sir John Herschel predicted, in 1823, that the orbital motion of the pair would "bring the three stars into

one straight line in 57 years." This prediction was fulfilled in 1887, when measures by Mr. Tarrant showed that the three stars were exactly in a straight line.

Castor.—This famous star already mentioned has been known to be double since 1718, when it was observed by Bradley and Pond. It was also observed by Maskelyne in 1759, and frequently by Sir W. Herschel from 1779 to 1803. Since that time it has been often measured by observers of double stars. Numerous orbits have been computed with periods ranging from 199 years by Mädler, to 1001 years by Doberck. Wilson found 983 years, and Thiele 997 years, so that the longest periods would seem to be the best. Mr. Mann has, however, recently found a period of only $265\frac{3}{4}$ years—another example of the difficulty of computing an orbit for these slow-moving binaries.

In addition to those for which orbits more or less satisfactory have been computed, there are many other double stars which are known to be certainly binary, but owing to the small portion of the orbit which has been described since their discovery, it is not yet possible to compute an orbit with any approach to accuracy. Some of these must be left to the astronomers of future generations. All that we can do at present is to measure them carefully at intervals, and hand these measures down to posterity. This is now being done by several observers, and the astronomers of the twentieth century will perhaps be grateful to them for their labours.

If the distance of a binary star from the Earth can be determined, we can find from the computed orbit the actual dimensions of the system. The combined mass of the component stars can thus be found in terms of the Sun's mass, by a simple mathematical calculation. This may be done by an extension of Kepler's third law of planetary motion. The distances of only a few of the binary stars have hitherto been ascertained with any approach to accuracy, but the masses deduced from these results are very interesting and suggestive. Assuming the most reliable measures of distance, and the best orbits computed for the following binary stars—η Cassiopeiæ, 40 Eridani, α Centauri, 70 Ophiuchi, and 61 Cygni—I find a total mass for these five systems of 11½ times the mass of the Sun, or an average of about 2⅓ for each system. Hence we have the average mass of each component of these five stellar systems not differing much from the Sun's mass, indicating that they are suns comparable with our own. In some other binaries, however, the mass is greater, and in some less than that of the Sun.

The close binary stars recently discovered by the spectroscope seem to form a distinct class of revolving suns. Their periods are so short compared with those of the systems visually double, which we have been considering in the present article, that we can hardly rank them in the same class. Their periods of revolution are reckoned by days instead of years, and consequently the components are so close that no telescope could ever have revealed their existence. Their individual components are as invisible to a powerful telescope as a telescopic "double star" is to the naked eye. Some account of these most interesting and remarkable objects will be found in the next chapter.

IX.

WEIGHING THE STARS.

SOME very interesting results have recently been obtained with reference to the weight of certain stars. It may be asked what is meant by weighing a star? How is it possible to calculate the weight of those far-off suns, the distance of which from the Earth is so great that only in a few cases can it be measured with any approach to accuracy? In the case of a *single* star, that is a star unaccompanied by a physically-connected companion, the calculation is impossible. Even if we knew the star's distance to a single mile, this knowledge would not help us to calculate its size and weight. The reason of this is that the fixed stars have no *apparent* dimensions. Even when examined with the highest powers of our largest telescopes, they still appear as mere points of light—minute discs of no measurable diameter. Hence their *real* diameter remains unknown. Even their relative brilliancy does not help us in the matter. For the stellar distances hitherto determined show that the brightest stars are not always the nearest to the earth. The nearest of them all—Alpha Centauri—is certainly one of the brightest; but, on the other hand, Arcturus, a star of about the same brilliancy as Alpha Centauri, is—if the measures of its distance are reliable—at a distance about 25 times greater than that of 61 Cygni, a star of only the fifth magnitude! This latter star is actually a little nearer to us than the brilliant Sirius, "the monarch of the skies."

In the case of a binary or revolving double star, however, the case is different. Although we cannot measure the actual diameter of the discs of the component stars, we can measure the distance between them in seconds of arc, and then—if their distance from the Earth can be determined—we are enabled to calculate by Kepler's third law of orbital motion, the sum of the masses of the components in terms of the Sun's mass.

The components of a double star may, however, be so close that they cannot be separated by the highest powers of our largest telescopes. We cannot therefore, in these cases, measure the distance between the components. To all intents and purposes they are to the telescopic observer single stars, and the fact of their duplicity would remain undetected.

But here a new method of research, discovered in recent years, comes to our aid. By means of the spectroscope we can determine the rate in miles per second at which a star is approaching or receding from the Earth. If then a star, apparently single in the telescope, consists in reality of two close companions revolving round each other in a short period, we can find in some cases the velocity of the components in miles per second, although we know nothing of the star's distance from the Earth. For, suppose the plane of the stellar orbit to pass through the Earth, or nearly so. Then, when the line joining the components is at right angles to the line of sight, one of the stars will be rapidly approaching the eye, and the other receding from it. All the dark lines in the spectrum of the first star will consequently be displaced towards the blue end of the spectrum, while those of the second will be equally shifted towards the red end—if the masses of the components are equal. Each line will therefore appear double, and from the observed distance between them we can easily compute the velocity. When the motion becomes perpendicular to the line of sight, the motion to and from the eye ceases, and the lines again become single. We have then merely to determine the times at which the lines appear single and double. As the lines will evidently double twice during each revolution, we must double the observed interval to obtain the period of revolution of one component round the other. The velocity and period thus found, enable us at once to compute the actual dimensions of the system in miles, and its mass with reference to that of the Sun.

In the course of spectroscopic researches on stellar spectra, undertaken at the Harvard Observatory for the "Henry Draper Memorial," Professor Pickering found that the calcium line K in the spectrum of the star ζ in Ursa Major, more popularly known as Mizar—the middle star in the "tail" of the Great Bear or handle of "the Plough"—appeared at times double, while on other occasions it was seen single and well defined. Other lines of the spectrum showed a similar variation. The doubling of the spectral lines was found to recur at regular intervals of about 52 days, thus indicating that the star was in reality a close double, with the components so close that no telescope yet constructed has hitherto been able to reveal its duplicity. Photographs of the spectrum of Mizar, taken on 70 nights in 1887—1889, show that the relative orbital velocity is about 100 miles a second, and the period of revolution of one component round the other about 104 days. From the observed dates on which the spectral lines appeared double, Professor Pickering predicted that they would be again double on or about December 9, 1889. This prediction was duly fulfilled on December 8, thus proving the reality of the discovery. Assuming that the orbit is circular, with its plane passing through the Earth, or nearly so, he finds that the distance between the components is about 143,000,000 miles, or about the distance of Mars from the Sun, and their combined mass about 40 times the mass of the Sun. Considering the brightness of the star and its probably vast distance from the Earth, this great mass is not very surprising. Mizar has long been known as a wide double star, the companion being about the fourth magnitude, and visible with a small telescope. Its duplicity was discovered by Riccioli in 1650, and it was measured by Bradley in 1755. It was the first pair photographed by the American astronomer Bond. It must now be looked upon as a triple star. Close to it is a fifth magnitude star known as Alcor, which is visible to the naked eye, and was considered by the ancients as a test of keen vision. It is now, however, plain enough to good eyesight, and is sometimes spoken of as a "naked eye double." Mizar is therefore a most interesting star: double to the naked eye, a closer double with a moderate telescope, and the primary star again double to the eye of the spectroscope. Between Mizar and Alcor is an eighth magnitude star, discovered by Einmart in 1691.

Professor Pickering thinks that the greatest distance between the close components of Mizar may perhaps be about $1\frac{1}{2}$ times its annual parallax, and is probably far too small to be ever detected by any telescope. Klinkerfues found for this star a very small parallax, indicating a distance of about five million times the Sun's distance from the Earth, or a journey for light of about 76 years!

The spectroscope has thus enabled us to discover the existence of an invisible body! If the orbit is slightly inclined to the line of sight, the dimensions and corresponding mass of the system would be increased. It seems improbable that the plane of motion passes *exactly* through the Earth, for in that case there would be an occultation of one component by the other twice in the course of each revolution, which would probably produce some diminution in the light of the star, as in the case of variable stars of the Algol type. I am not aware that any such regular variability has been observed in the light of Mizar. We must therefore conclude that the mass of the system is really more than that computed by Professor Pickering.

A similar spectroscopic result has been found in the case of the bright star β Aurigæ, for which the observations indicate a period of about four days, with a distance between the components of about 8,000,000 miles. From these data I find that the combined mass of the components would be much less than in the case of Mizar—about five times that of the Sun. A similar variation was found to occur in the star 44 Ophiuchi. This star has been strongly suspected of fluctuations in its light, and it may possibly be a variable of the Algol type. Professor Vogel finds a similar motion in the bright star Spica (α Virginis)—the leading brilliant of the constellation Virgo, or the Virgin—with a period of about four days. Here, however, the lines are merely shifted, not doubled, or at least not distinctly so, as in Mizar and β Aurigæ. This indicates that one of the components is so faint that its spectrum is not seen, or only seen with difficulty, and that the observed motion is chiefly that of the brighter component. From the observed velocity—about 57 miles a second—Vogel computes that, for components of equal mass, the total mass of the system is 2·6 times that of the Sun, and that the distance between the components is about 6¼ millions of miles. In addition to this orbital motion, the observations indicate that the system is approaching the Sun at the rate of 9·2 miles a second. "Taking the most probable value for the star's parallax, the angular separation of the stars would be 0·014″, a quantity far too small to be detected by the most powerful telescopes."

With reference to the Algol variables, it has long been suspected that the decrease in their light at minimum might possibly be due to the interposition of a dark eclipsing satellite of large size. This periodical variation in the light of Algol itself seems to have been known to the ancients, as its name implies the "Demon star." The true character of its variation was, however, first determined by Goodricke in 1782, when its period from minimum to minimum of light was 2 days, 20 hours, 48 minutes, 59½ seconds. This has slowly diminished to the present value of 2 days, 20 hours, 48 minutes, 51 seconds, according to a recent investigation by Dr. Chandler. Some few years since Professor Pickering undertook a mathematical investigation of the case, and showed that a dark eclipsing satellite revolving in a nearly circular orbit round Algol, in the period indicated by the light variation, would explain the observed phenomenon within the limits of errors of observation, and he pointed out that the orbit of the bright star might be determined by spectroscopic observations without any knowledge of the star's distance from the Earth.

Assuming the correctness of this hypothesis, and taking into account the observed diminution at minimum, Mr. Maxwell Hall computed that the density of Algol is only one-fourth that of water. From spectroscopic observations made by Professor Vogel at Potsdam in 1888 and 1889, he concludes that the decrease of light is really due to an eclipsing satellite. He found that before the minimum of light the bright star is receding from the Earth at the rate of 24½ miles a second, and after the minimum, approaching with a velocity of 28½ miles. The difference in the observed velocities is due to a motion of translation of the system in space at the rate of about 2⅓ miles per second towards the Earth. Assuming the orbit to be circular, with the plane passing through the Earth, Professor Vogel computes the diameter of Algol at 1,061,000 miles, and that of the dark companion 830,300 miles, with a distance between them of 3,230,000 miles from centre to centre. He makes the mass of Algol four-ninths of the Sun's mass, and that of the companion twoninths, or a combined mass equal to two-thirds of the mass of the Sun. Taking the Sun's density as 1·44, and its diameter 866,000 miles, I find that the above dimensions give a mean density for the components of Algol of about one-third of that of water, not differing much from Maxwell Hall's result, and showing the correctness of his conclusion, that "in the case of the components of Algol, as Mr. Lockyer argues in the case of the Sun, we are undoubtedly dealing with masses of gas." The spectrum of Algol is of the first or Sirian type, all the spectral lines being faint except those of hydrogen, a type of spectrum which seems to indicate that the star is very hot, and therefore probably in the gaseous state. This confirms the conclusion as to its density derived from the spectroscopic evidence of the orbital motion, and proves the correctness of the hypothesis that the variation of light is due to a dark eclipsing satellite.

Professor Vogel assumes that both the components of the Algol system have the same density. But if this be so, we have the curious case of two bodies not differing largely in volume, of which one is intensely hot and the other nearly a dark body. Vogel does not, however, consider it necessary to assume that the companion is *absolutely* dark, but to agree with the observed variation the light of the satellite cannot be greater than one-eightieth of that of Algol itself. As the spectrum of Algol is of the first type, we may perhaps conclude that the intensity of its light is greater than that of our Sun. The light emitted by the satellite may, therefore, possibly be equal to several thousand times the light of the full Moon without interfering with the hypothesis.

The brightness of Algol and its comparatively small mass might be taken to indicate a relative proximity to the Earth; but if its parallax were even one second of arc—a highly improbable value—the greatest distance between the components would amount to only one twenty-ninth of a second, a distance quite beyond the dividing power of even the largest telescopes. Probably its parallax does not exceed one-tenth of a second.

It is to be hoped that the spectroscopic method may be applied to other stars of the Algol type, but some of these are so faint that very large telescopes would be required for the purpose. The following are, however, sufficiently bright to repay examination with telescopes of moderate power: λ Tauri, magnitude 3½, and δ Libræ of the fifth magnitude. The others we must leave to the great Lick telescope, Dr. Common's 5-feet reflector, or the giant 40-inch refractor about to be erected at Chicago.

X.

ON THE MASS AND BRIGHTNESS OF BINARY STARS.

THE orbit of a binary star having been computed, and its distance from the earth determined, it is easy to calculate the combined mass of the components in terms of the Sun's mass. We can also compare the brightness of the star with that of the Sun, for as the brightness decreases as the square of the distance, we can compute how much the Sun's light would be reduced if removed to the distance of the star. Photometric comparisons have shown that the Sun's stellar magnitude is about —25·5, on a scale of which the "light ratio" is 2·512. In other words, the Sun is 25½ magnitudes brighter than a star of the zero magnitude, or 26½ magnitudes brighter than an average star of the first magnitude, like Altair or Spica. The parallax of some of the binary stars has been ascertained, and although the results found are perhaps in some cases of rather doubtful value, an examination of the mass and brightness indicated by the most careful measures of the distance may prove of interest to the reader.

We will take the stars in order of right ascension—

1. η Cassiopeiæ.—For this well-known binary star

a parallax of 0·3743″ has been found by Schweizer and Socoloff. Several orbits have been computed, none of which are quite satisfactory, but assuming Grüber's period of 195·235 years, and semi-axis major of 8·639″, I find the mass of the system equal to 0·32 of the Sun's mass. The star was measured 3·41 magnitude, with the photometer at Oxford, and 3·64 at Harvard. We may, therefore, assume its magnitude at 3·5. Taking the Sun's stellar magnitude at —25·5, I find that if placed at the distance indicated by the above parallax, the Sun would be reduced to a star of magnitude 3·2, or only slightly brighter than η Cassiopeiæ. As the companion is only 7½ magnitude, it will not appreciably affect the light of the star, and as the spectrum is of the second or solar type, it should be fairly comparable with the Sun. If the mass were equal to that of the Sun, the parallax would be 0·256″, and at this distance the Sun would be reduced to a fourth magnitude star. Struve found a parallax of 0·154″. Its comparatively large proper motion of about 1·2″ per annum would indicate a comparative proximity to our system.

2. 40 Eridani.—The binary companion of this triple star is of about the ninth magnitude, and is probably physically connected with the bright star, as all three have a common proper motion. A parallax of 0·223″ has been found by Professor Asaph Hall. This, combined with the orbit com-

puted for the binary pair by the present writer, gives a mass equal to the Sun's mass—a result which is remarkable, for the Sun, placed at the distance indicated by the parallax, would shine as a star of 4·3 magnitude, or about the brightness of the principal star of 40 Eridani. This result implies that the Sun is about 76 times brighter than the binary pair. Owing to the faintness of the binary star, the character of its spectrum has not been determined. Computed by a well-known formula, its "relative brightness" is very small, but only one orbit has yet been computed, and this will require revision when further measures are available. The proper motion of the system is very large, about 4·1″ per annum.

3. Sirius.—The great brilliancy of this star—the brightest in the heavens—naturally suggests a sun of great size. Recent investigations do not, however, favour this idea. Assuming a parallax of 0·39″ (about a mean of the results found by Elkin and Gill) and the elements of the orbit computed by the writer, the mass of the system would be 3·114 times the mass of the Sun. Placed at the distance of Sirius, the Sun would be reduced to a star of 3·1 magnitude. As Sirius is about one magnitude brighter than the zero magnitude, it follows that it is about four magnitudes, or about forty times brighter than the Sun would be in the same position. Were it of the same density and brightness as the

Sun, the mass found above would indicate that its diameter should be 1·463 the solar diameter, and its brightness 2·1324 the solar brightness. The spectrum is, however, of the first type, and the star is, therefore, not comparable with the Sun in brilliancy. The result would indicate that stars of the first, or Sirian type, are intrinsically brighter than the Sun.[1]

4. Castor.—Assuming a parallax of 0·198″ found by Johnson, and a period of 1001·21 years found by Doberck ($a = 7{\cdot}43''$), I find the sum of the masses of the components of Castor only 0·052692 of the Sun's mass, a result which would imply that the components are gaseous masses. Johnson's parallax is, however, of doubtful value. Placed at the distance indicated, the Sun would be reduced to a star of 4·5 magnitude. The magnitude of Castor is about 1·55, so that it is (according to the assumed parallax) about three magnitudes, or about sixteen times brighter than the Sun would be in the same position. The spectrum is of the first type, another example of the great brightness of the stars of this type. According to a well-known formula, the "relative brightness" of Castor is thirty-eight times that of the binary star ξ Ursæ Majoris, taken as a standard. The latter star has a spectrum of the second type.

5. α Centauri.—This famous star, the nearest of all the stars to the Earth, as far as is at present known, forms an object of especial interest, particu-

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[1] Or that they are of less density than our Sun.

larly as its spectrum is, according to Professor Pickering, of the second or solar type, although with some peculiarity. Combining Dr. Gill's parallax of 0·76″ with Downing's elements of the orbit (P = 76·222 years, a = 17·33″), I find that the mass of the system is 2·04 times the mass of the Sun.[1] Placed at the distance of α Centauri, the Sun would be reduced to a star of about 1·7 magnitude, or about one magnitude fainter than the star appears to us. This would indicate that α Centauri is about two and a half times brighter than the Sun, and its mass (if of the same density) about four times the solar mass. As, however, there is something peculiar about the spectrum, the density and intrinsic brightness of α Centauri may be somewhat different from that of the Sun.

6. 70 Ophiuchi.—This is another star which is fairly comparable with the Sun, as its spectrum is of the solar type, according to Vogel. The orbit found by the present writer (P = 87·84 years, a = 4·50″), combined with Krüger's parallax of 0·162″, gives for the combined mass of the components 2·777 times the mass of the Sun. The star was measured 4·11 magnitude with the photometer at Harvard Observatory. Placed at the distance indicated by the parallax, the Sun would be reduced to 5·0 magnitude. This would make 70 Ophiuchi about 2·27 times the brightness of the Sun. According to Dembowski there is a difference of 1·7 magnitude between the

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[1] See p. 61, for a more accurate result.

components. If we assume that each has the same density as the Sun, I find that the combined mass of the two stars would be 2·825 times the solar mass, which agrees closely with the result found from the orbit. We may, therefore, conclude that Krüger's parallax for this star is not far from the truth. The diameters of the components would be about 1,188,000 miles, and 542,000 miles, and the distance between them 27·77 times the Sun's distance from the Earth, or somewhat less than the distance of Neptune from the Sun.

7. 85 Pegasi.—For this binary pair, a somewhat doubtful parallax of 0·054″, found by Brünnow, combined with Schaeberle's elements of the orbit ($P = 22{\cdot}3$ years, $a = 0{\cdot}96''$), gives a mass of 11·3 times the Sun's mass. Placed at the distance indicated, the Sun would be reduced to a star of 7·41 magnitude. 85 Pegasi was measured 5·83 magnitude with the photometer at Harvard, so that the star is 1·58 magnitude, or 4·286 times brighter than the Sun would be at the same distance. If of the same density, its mass would, therefore, be 8·872 times the solar mass, a result not differing very widely from that found from the orbit. As, however, I have no information of the character of the star's spectrum, I cannot say whether or not it is comparable with the Sun.

It seems to be still very doubtful whether 61 Cygni is really a binary star, but assuming a parallax of 0·45″, and the star's magnitude at 5·11, as measured at Harvard, I find that the Sun is about 8·39 times as bright as 61 Cygni, and its mass, therefore, considerably greater. The star has, according to Professor Pickering, a peculiar spectrum of the solar type.

Let us now consider the close binary stars recently discovered with the spectroscope, and which are known as "spectroscopic binaries." With reference to Algol, which may be considered as a binary pair, in which one of the components is a dark body, Professor Vogel finds that the combined mass of the system is about two-thirds of the Sun's mass. From the dimensions he gives for the components, I find that their mean density is about one-third that of water, so that they are probably gaseous bodies. As the parallax of this star has not yet been determined, we cannot say what the Sun's magnitude would be if placed at the star's distance, but as the spectrum of Algol is of the first or Sirian type, we may conclude that it is bright in proportion to its mass.

For ζ Ursæ Majoris (Mizar) Professor Pickering finds a mass equal to forty times the mass of the Sun. Klinkerfues found a parallax of about 0·045″ for this star. At this distance the Sun would be reduced to a star of only 7·8 magnitude. The Harvard measure of ζ Ursæ is 2·38. It is therefore 5·42 magnitudes, or 147 times brighter than the Sun would be at the same distance. It should therefore be, if of the same density, 1787 times the mass of the Sun. But the spectrum is of the first type, and the star is therefore not comparable with the Sun in its physical constitution. We have here another example of great brightness in proportion to mass.

β Aurigæ was discovered to be a close binary with the spectroscope at Harvard Observatory, and the discovery has been fully confirmed by the observations of Professor Vogel at Potsdam. The period is about four days, and the distance between the components about 8,000,000 miles. From these data I find that the mass of the system is about five times the mass of the Sun. Recent photographic measurements by Professor Pritchard at Oxford have yielded a parallax of 0·059″ and 0·065″.[1] Taking a mean of these results, or 0·062″, we have the Sun reduced to 7·17 magnitude if placed at the distance of the star. β Aurigæ was measured 1·94 magnitude at Oxford and 2·07 at Harvard. We may therefore assume its magnitude at 2·00. This gives a difference of 5·17 magnitudes between the light of the Sun and that of β Aurigæ. In other words, β Aurigæ is 117 times brighter than the Sun would be if placed in the same position. If therefore of the same intrinsic brightness of surface, its diameter would be 10·8 times the diameter of the Sun, and its volume 1265 times the Sun's volume. We see, therefore, that—like Sirius—this star is very much brighter than the Sun in proportion to its mass. As the spectrum of β Aurigæ is of the first or Sirian type, we have here another example

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[1] *Observatory*, June 1891.

of great brilliancy in proportion to mass, a feature which seems characteristic of all stars of the Sirian type.

Spica.—The spectroscopic observations of this bright star indicate a mass of about two and a half times the mass of the Sun. The parallax has not yet been well determined (Brioschi found a negative parallax), but judging from its small proper motion, the star's distance is probably very great. As it is a standard star of first magnitude, its brightness would seem to be enormous in proportion to its mass, and here again we have a spectrum of the Sirian type.

We may therefore conclude that binary stars with spectra of the first type—and probably all stars of this type—are very bright in proportion to their mass, while those showing spectra of the second or solar type are intrinsically much less luminous, and have a brightness approximately proportional to their mass.

Mr. Ranyard remarks in *Knowledge*[1]—

"Many of the parallaxes made use of by Mr. Gore in these calculations are no doubt extremely doubtful. But in such an inquiry, even the roughest estimates are of value. The evidence collected tends to indicate that stars of the Sirian type are either less dense than the Sun—that is, that they are in an earlier stage of condensation—or that their photospheres are more brilliant, area for area, than the solar photosphere."

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[1] Nov. 1891.

XI

THE ORIGIN OF DOUBLE STARS.

THERE are two classes of double stars known to astronomers, namely "optical doubles," and "binary," or revolving double stars. In the optical doubles the components are accidentally placed nearly in the same line of sight as seen from the Earth, one star being situated at possibly a vast distance behind the other in space. In such pairs, one of the stars is usually much fainter than the other. But even if the stars are of nearly equal brilliancy they may possibly be separated by a great distance, although they apparently seem close together owing to their great distance from the Earth. In either case the absence of any relative motion indicates that there is no physical connection between them. Binary stars are those which have a relative motion, one star revolving round the other in a longer or shorter period. This relative motion shows that the stars are physically connected, and lie at practically the same distance from the Earth. They are *real* double stars, systems of suns in space revolving according to the laws of gravitation round their common centre of gravity in the same way that the Earth revolves round the Sun. It is true that an *apparent* relative motion may exist without any physical connection between the stars; but in this case the motion is always in a straight line, indicating that one of the stars has a rapid motion through space which carries it past the other star. In such double stars the apparent distance between them will, in the course of time, become so considerable that they will cease to form even "optical doubles." On the other hand the motion may tend for some years to bring the pair closer together, but in either case the rectilinear motion, which careful measures show, is sufficient to distinguish between these and real binary stars.

The origin of optical double stars is therefore obvious. They owe their existence to their apparent position in space, their accidental situation with reference to the observer's line of sight. Such double stars probably exist by thousands in the Milky Way, and in star clusters, and do not deserve the title of "double stars" at all; some of them form favourite subjects of observation with amateur telescopists, but they are of no real interest to astronomers.

The origin of binary or real double stars is not so obvious. Some have suggested that two stars travelling through space may have accidentally come together, and that the larger has "captured" the smaller and compelled it to revolve round it by the force of its attraction. But such an hypothesis is very unsatisfactory and improbable. Although most of the stars are probably in motion, space is of such vast extent that the probability of two passing so close to each other as to come under the influence of their mutual attraction and permanently revolve in a closed orbit is very small. It is of course possible that in a few cases binary stars may have had their origin in the fortuitous meeting of two stars, but such an occurrence must be very rare, and we may therefore dismiss this hypothesis as quite untenable.

According to the Nebular Theory of Laplace, celestial systems, like the Solar System, have had their origin in the gradual consolidation of a rotating nebulous mass. The evidence in favour of this theory, is so strong that it is now very generally accepted by astronomers, although the method of formation of the separate planets and satellites from the parent mass has formed the subject of much discussion. Admitting the general accuracy of Laplace's theory, the question naturally suggests itself—Have the binary stars had a similar origin? Have these remarkable systems been consolidated in the course of ages from a gaseous nebula? The difference between the Solar System and a binary star is very marked. In the Solar System we have a large central body, the Sun, with a number of small bodies revolving round it, the mass of the central body being very much greater than the combined mass of all the planets and satellites forming the system. In the binary stars, however, we have two (and in some cases three) bodies of large mass revolving round their common centre of gravity. There is another point of difference between the two systems. In the Solar System the orbits of the planets are—as a rule—nearly circular, or in mathematical language the eccentricity of the elliptic orbits they describe round the Sun is small. On the other hand, the eccentricity of the binary star orbits is usually large. The average eccentricity of the orbits of the larger planets and their satellites is only 0·0089, while that of 70 binary stars, for which orbits have been computed, is 0·45, or nearly 12 times greater. This difference is remarkable, and requires explanation if we suppose that both classes of systems had their origin in masses of nebulous matter.

Some years ago Professor G. H. Darwin showed that the formation of the Moon was an exception to the ordinary evolution of planets as supposed by the Nebular Theory. He showed that the Moon's orbit and rotation on its axis were considerably modified by the effects of Tidal Friction acting between the Earth and Moon. This principle of Tidal Friction has been applied to the binary stars in a remarkable investigation recently undertaken by Dr. T. J. J. See, who has made a rigorous mathematical examination of the subject, and has arrived at some very interesting results. He concludes that the binary stars had their origin in a rotating nebulous mass. He shows that when the speed of the rotation increases—owing to consolidation—and reaches a certain point where the equilibrium "breaks down," the parent mass will divide by "fission" into two comparable masses, and that these masses consolidating will—in the course of ages—develop into binary stars. He considers that the discovery of double nebulæ by Sir John Herschel supports this view, and certainly some of the drawings of these nebulæ are very remarkable and suggestive.

Considering the simplest case of a nebulæ dividing by "fission" into two nearly equal masses, Dr. See discusses the effects of Tidal Friction on the subsequent motion of the two bodies. As the two masses are gaseous, the effects of tidal action will not be confined—as in the case of a rigid body like the Earth—merely to the surface of the bodies, but "will extend throughout the whole mass." These are called "bodily tides." Now suppose the orbit described by the two revolving masses to have at first a small eccentricity, what will be the effect of these bodily tides on the motion of the two bodies round their common centre of gravity? The mathematical investigation of this problem is of course complicated and difficult, and its details could not be reproduced in an article like the present. We may say, however, that the tide-raising force varies inversely as the cube of the distance of the body which generates the tides, and Dr. See shows that the result of this, combined with the increase in density of the gaseous masses from the surface towards the centre, would be that the major axis of the orbit and the eccentricity will first slightly decrease and then gradually increase. After attaining a maximum, the eccentricity will again begin to diminish, and will finally disappear owing to exhaustion of rotation in the bodies and loss of energy in the system. Taking an ideal case of two spheroidal masses each having three times the mass of the Sun, and having a rotation period which would produce an ellipticity or polar compression of 0·4, Dr. See supposed these masses to be revolving at a distance equal to that of Neptune from the Sun (about 30 times the Sun's distance from the Earth) in an orbit of which the eccentricity is 0·1. He then found by calculation that Tidal Friction would increase the semi-axis major to about 49 times the Earth's distance from the Sun, and also the eccentricity up to a maximum of 0·57. After the maximum was reached, the eccentricity would again diminish and would finally vanish when the mean distance between the revolving masses was about 51 times the Sun's distance from the Earth. But this gradual change would of course require vast ages for its evolution, and probably before this state of rigid equilibrium is reached, the bodies would have so far consolidated as to lose their light and become invisible.

Some of the binary star orbits have small eccentricities. These may possibly have recently emerged from the nebulous state, or, on the other hand, they may be very ancient systems which are far advanced towards their final stage of equilibrium. If we knew the distance of these exceptional orbits we might perhaps be able to form some idea as to which of these suppositions is more probably correct in any particular case. For example, the orbit of the binary star 40 Eridani has a small eccentricity. Its distance from the Earth has been determined, so that we can calculate its mass in terms of the Sun's mass. The result is that the combined mass of the components is about equal to that of the Sun. This binary—which forms a distant companion to the fourth magnitude star 40 (o^2) Eridani—is only of the ninth magnitude. Placed at the same distance as the star, I find that the Sun would be reduced in brightness to a star of about 4⅓ magnitude. The Sun is therefore about 67 times brighter than the binary star, although of about the same mass. I find also that, computed by another well-known method, which is independent of the star's distance from the Earth, the "relative brightness" of 40 Eridani is very small compared with that of other binary stars. These results suggest that the binary companion to 40 Eridani has lost a considerable portion of its primitive light, and is probably far advanced on the road to complete extinction of its luminosity. On the other hand ζ Sagittarii, the orbit of which has also a small eccentricity, is a tolerably bright star—third magnitude. The distance of this star from the Earth has not yet been determined, but it probably lies at a great distance. If this be so we have here, possibly, an example of a brilliant star and one in an early stage of its life history. Its "relative brightness," compared with other binary stars, is high.

Whether binary star systems or systems formed on the model of the Solar System are more numerous in the sidereal universe is an interesting question, but one not easy to answer satisfactorily. The impossibility of detecting, even with the largest telescopes, planets revolving round any of the stars—if such planets exist—renders it impossible to decide whether any systems similar to our planetary system exist among the stars. We can, however, estimate the relative number of binary stars. The total number of so-called double stars now known to astronomers is probably ten or twelve thousand. These include stars down to the tenth magnitude, and some even fainter. We may perhaps estimate the number as 10,000 to the tenth magnitude. Now the number of stars to the tenth magnitude in both hemispheres is about 600,000. This gives one double star in 60. Of the 10,000 so-called double stars, we may perhaps assume that 1000 are certainly binary stars. Hence we have one binary star in every 600 known stars. We may, therefore, conclude that the great majority of the stars are single, and that whether these single stars form the centres of planetary systems similar to the Solar System or not, binary systems are certainly not the rule in the sidereal universe.

XII.

VARIABLE DOUBLE STARS.

VARIABLE stars are not as a rule close doubles, neither do the wider double stars include many examples of the variable class. Among the known binary or revolving double stars I do not know of a single instance—with the possible exception of 36 Andromedæ—of undoubted variation, although in some cases there exists a strong suspicion of inconstancy of light.

In speaking of double stars I refer to those which are actually seen to be double in good telescopes, for on the eclipsing satellite theory the variables of the Algol type must be considered as binary stars with very short periods, and with the component stars so close that even the largest telescopes yet constructed fail to show them as anything but single stars.

To the above rules there are, however, some notable exceptions. Perhaps the most remarkable instance of a variable star being also a close double is η Geminorum. The variability of this third magnitude star was detected by Schmidt in 1865, and the reality of its fluctuations has been confirmed by Schönfeld and other observers, including the present writer. The total variation amounts to about one magnitude in a period which is somewhat irregular, varying in length from 135 to 151 days, according to Schmidt. Occasionally, however, its light remains constant, or nearly so, for several weeks at a time. The colour of the star is reddish-yellow, and its spectrum a fine one of Secchi's third type, a type to which many of the long period variables belong. In 1881 Mr. Burnham, the eminent American astronomer and discoverer of so many double stars, found the star to be a close double, the companion being of about the tenth magnitude, and distant less than 1″ of arc from its comparatively brilliant primary. The difference of light is therefore about seven magnitudes, indicating that the bright star is about 630 times brighter than the faint one. Mr. Burnham speaks of it as "a splendid unequal pair, and likely to prove an interesting system." Time will of course be required to prove the accuracy of this prediction, but should its binary character be established it will form a most interesting object, especially as hitherto no binary star has been found with a spectrum of the third type.

Another variable star with a close companion is the short period variable S (15) Monocerotis. This star is the principal one of a small cluster known to astronomers as Herschel VIII. 5. The variable star, which fluctuates from about fifth magnitude to 5½, has two faint companions of about the ninth and eleventh magnitude. The ninth magnitude is distant about 3″ of arc from the brighter star, and the eleventh magnitude about 17½″, and both may possibly have a physical connection with their primary. If the close pair are really in motion, the period of revolution must be very long, as a measure by Mr. Tarrant in 1888 shows an angular change of only 6° since its discovery by Struve in 1832. The colours have been noted as greenish, and blue or pale grey. The spectrum is of the first or Sirian type. Additional interest is attached to this object from the fact that a distant companion (at about 76″ of arc) has been strongly suspected of variation in light from 8½ to twelfth magnitude. Observations by Mr. Tarrant in March and April 1888 tend to confirm this suspicion, as they show a difference in the estimates of its brightness of about 1½ magnitude in about three weeks. This object deserves more careful observation than it has hitherto received. A variable star with a variable companion would indeed be an interesting object.

A similar suspicion of variability is attached to a distant companion to the famous variable star Algol. This faint companion lies about 80″ of arc to the south of Algol. It was discovered in 1787 by Schroter, who suspected variation in its light; and observations in recent years tend to the same conclusion. In the early part of 1874 one observer failed to see any trace of it with a 7-inch refractor; but on September 9 of the same year, it was distinctly visible in the same instrument.[1] Sadler considers it probably variable from the tenth to the fourteenth magnitude in some short period. Three other faint companions were found by Burnham, one of them being distant less than 11″ from the suspected variable, which was estimated of the tenth magnitude by Burnham in September 1877, the companion being rated about 12½ on the same evening. The others are of about the thirteenth magnitude, and form good comparison stars for the suspected variable, which Franks found "easy enough" with an 11¼-inch reflector on January 11, 1885, and about two magnitudes brighter than Burnham's companion.

The well-known variable star 68 (*u*) Herculis has also a tolerably close companion of about the tenth magnitude, distant about 4″ in 1878. Here we have also a difference of brightness of about five magnitudes, or a ratio of 100 to 1 in the relative brilliancy of the components.

Another interesting case is that of the well-known variable α Herculis. This is a double star with components of about the third and sixth magnitudes, at a distance of about 4½″ of arc. Measures of position from 1782 to 1876 show little or no change, and indicate no physical connection. Possibly the

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[1] *Nature*, Feb. 20, 1879.

fainter companion may be much farther from us than the brighter star. The colours are orange, and emerald or bluish-green, and the spectrum is a splendid specimen of the third type. There seems to be some little doubt as to which of the components fluctuates in light; Sir W. Herschel and Argelander considered the brighter star to be the variable one, whereas Struve thought the variation was due to the fluctuations of the fainter component from the fifth to the seventh magnitude. It is not so easy to decide a question of this kind as might at first be supposed. Viewing a pair like this with a magnifying power sufficiently high to satisfactorily separate the components, they are seen in a small telescopic field of view completely isolated from other neighbouring stars of nearly equal lustre with which they might be compared. Observations with a wedge photometer might perhaps settle the question. Judging from the colours and spectrum, my own opinion is that the brighter star is the variable, and that possibly the fainter star may have merely an optical, and not a physical, connection with its brighter companion.

Another close double star which is almost certainly variable is Y Virginis (near 68 (i) Virginis). It seems to have no regular period, but, though usually of about the sixth magnitude, it was observed by Schmidt as bright as 4½ magnitude on June 6, 1866. The Cordoba observations in subsequent years seem to confirm the variability, but possibly the star may remain constant in its light for lengthened periods. In 1879 Burnham found it to be a very close double star, the components being nearly of equal brightness, and separated by only half a second of arc. Observations in recent years do not give much evidence in favour of orbital motion. The colour of the star is yellowish-white, and the spectrum of the Sirian type.

Among variables with distant companions may be mentioned T Cygni, to which Burnham found a twelfth magnitude companion at 10″; the Algol variable U Ophiuchi, which has a very faint companion at a distance of about 20½″; U ("Nova") Orionis, which has a 10½ magnitude attendant at 30″; δ Orionis, a second magnitude star with a very faint companion at about 34″, and a seventh magnitude at 53″; and the short period variable δ Cephii with a seventh magnitude companion at 48″.

Among stars certainly binary there is one, 36 Andromedæ (Struve 73), which is, according to Schmidt, variable to a small extent in periods varying from 40 to 125 days, but I am not aware that this variability has been confirmed by other observers. The components are of about the sixth and seventh magnitude, and the present distance between them a little over 1″ of arc. Dr. Doberck has computed an orbit for this pair, and finds a period of about 349 years.

Among the numerous stars which have been suspected of variable light, but which have not yet been admitted into the ranks of the regular variables, there are some interesting cases. The components of the well-known binary star γ Virginis have been suspected of alternate variation in brightness. In the years 1851 and 1852 Struve found the components sometimes exactly equal and sometimes differing by nearly three-fourths of a magnitude in favour of the southern star. In the years 1825 to 1832 he found the other component certainly the brighter. Franks found the southern star half a magnitude the brighter on March 28, 1885. Struve's suspicion seems to be confirmed by the observations of Fletcher, and the point seems deserving of more attention than it has hitherto received. An estimate of relative brightness might easily be made by those observers who measure at intervals the position of the components, and in this way interesting results might be obtained.

The companion of the double star Struve 547 has been suspected of variable light. It was estimated as 11½ magnitude by Struve in the years 1829 and 1832; but Dembowski could not see it in 1865. Burnham, although gifted with keen eyesight, failed to find it in 1873 and 1876. Gledhill was equally unsuccessful in 1879. The companion was, however, seen and measured by Mädler in 1845, by Burnham in 1877, 1879, 1880, and 1881, and by Gledhill in 1880. The latter observer found the distance between the components about 2½″, and his measure of angle (15·8°) seems to show some angular motion since its discovery by Struve in 1831.

A similar case is found in Struve 1058, in which the eleventh magnitude companion to an 8½ magnitude star was measured by Burnham, in 1879 and 1881, but could not be found by Dembowski in 1865, nor by Burnham in 1874, 1875, and 1878.

In the double star Struve 1517 the observations of Struve, O. Struve, and Secchi seem to point to some variation in the relative brightness of the components. The measures of position since 1832 indicate a slow angular motion in the pair, which have also a common proper motion through space.

Struve 1932 is a double star in Corona Borealis, of which the components were estimated 5·6 and 6·1 magnitudes by Struve, 6 and 6·5 by Secchi, and 6·9 and 7·2 by Dembowski. Struve suspected variability, and my own observations with a binocular in the years 1885—1887 apparently show a small variation of light. The measures indicate a marked angular motion since its discovery in 1830, so that the pair is probably a binary.

The components of 36 Ophiuchi were rated 4½ and 6½ magnitude by Smyth in 1831. Sir J. Herschel estimated them both as sixth magnitude in 1834 and 1837. Dawes rated them both fifth magnitude in 1841, and so they were seen by Jacob in 1846. In 1854 Webb found them "nearly equal, about 6·5, Smyth's smaller perhaps rather the larger." In 1875 in India I noted them as "Both yellow, and almost exactly equal. The following star (Smyth's brighter component) if anything rather the brighter of the two." The measures show a well-marked angular motion of the pair, which is probably a binary, as the components have a considerable common proper motion of about 1¼″ per annum. Curious to say, they are accompanied in their flight through space by the star 30 Scorpii, which is distant no less than 13′ of arc from the binary pair.

One of the components of the double star O. Struve 256 has been suspected of variable light. They were rated 7·2 and 7·6 in 1848 by O. Struve, who made the *preceding* star in the field his primary. In 1867 Dembowski seems to have seen the *following* component the brighter, as his measures of position angle show. Perrotin in 1885 agrees with O. Struve, and measured the position angle from the *preceding* star. On August 22, 1887, an occultation of the star was observed by Mr. J. Tebbutt at Windsor, New South Wales. He had not at the time identified the star, and was not aware that it was double. About three-fourths of the star's light at first suddenly disappeared, and about two seconds later "the rest of its light, which resembled a blurred star of the ninth magnitude, vanished quite as suddenly." This observation seems to show that on the date of Tebbutt's observation, the *preceding* star was *considerably* the brighter of the two components, and compared with Dembowski's measures, appears clearly to indicate variable light in one or other of the component stars. The star is probably a binary.

XIII.

ON SOME PECULIARITIES OF THE VARIABLE STARS.

THE long period Variable Stars have periods ranging from 100 to over 700 days, and with fluctuations of light from about one magnitude to over eight magnitudes. Dividing these into groups, I find that the maximum number is found among those with periods of 275 to 375 days. Chandler finds that the longer the period the redder the tint. According to Chandler's estimates of their colours, the reddest of all are—in order—R Leporis (period 436 days), V Cygni (461 days), S Cephei (484 days), R Sculptoris (207 days), and V Hydræ (575 days). Dunér, however, makes the reddest variables V Hydræ, S Aurigæ, and V Cygni.

The Variable Stars of short period include 19 stars with periods of less than 30 days. Of these I find that four have periods of under five days, eight have periods of under eight days, three have periods of less than 11 days, and three under 18 days. The maximum number is, therefore, under eight days. The variation of light is usually small. In but few cases does it much exceed one magnitude, and in several it is less. In some, as in β Lyræ, ζ Geminorum, and η Aquilæ, all the changes may be observed with the naked eye alone, while in others an opera-glass is necessary to follow their fluctuations.

The great majority of these short period variables are found in a zone which nearly follows the course of the Milky Way. Another curious peculiarity connected with their distribution is that most of them lie—like the Temporary Stars—in the *following* semicircle, that is, between 12 h. and 24 h. of Right Ascension. The most remarkable exception to this rule seems to be ζ Geminorum, which has a period of about 10 days 3¾ hours. All the Variable Stars of this class with shorter periods than ζ Geminorum conform to this rule, except S (15) Monocerotis, of which the *regular* variability seems very doubtful. It is not easy to conjecture the cause of this peculiarity of position, for the Variable Stars of other classes are found scattered indifferently over all parts of the celestial vault.

Of the Algol type variables the brightest are Algol, λ Tauri, and δ Libræ. The others are much fainter, only two being visible to the naked eye when at their normal brightness. Chandler finds that "the shorter the period of the star the higher the ratio which the time of oscillation bears to the entire period." Thus, in U Ophiuchi, with a period of about 20 hours, the light changes occupy five hours, or about one-fourth of the period, while in S Cancri, of which the period is about 227½ hours, the fluctuations of light occupy 21½ hours, or about one-tenth of the period. All the Algol variables are white, or only slightly tinted, and it would therefore seem to be hopeless to look for variables of this class among the highly-coloured stars. In all cases in which the stars have been examined with the spectroscope the spectrum is found to be of the first or Sirian type, another peculiarity worthy of notice. The same remark applies to the stars which have been found by the spectroscope to be close binaries, such as ζ Ursæ Majoris, β Aurigæ, and Spica. These have spectra of the first type, and may be considered as Algol variables in which the plane of the orbit does not pass through the Earth.

If we assume that the apparent variation of the Algol variables is due to the transit of a dark or nearly dark satellite, we seem logically compelled to conclude that these stars are not really variable at all in the true meaning of the word. Their light is merely obscured at minimum in the same way that the Sun's light is reduced during a partial Solar eclipse. It is simply a case of occultation of one star by another, and probably these so-called variables might more correctly be classed among the binary stars. If, like the Temporary Stars, we reject the Algol variables, we have then only three classes of true Variable Stars, viz.:—(1) stars with regular periods of considerable length, (2) irregular variables, and (3) variables of short period.

With reference to the general distribution of the Variable Stars, I plotted some years since all the known variables on one chart for each hemisphere, and I do not find any *very* marked tendency to aggregation in any particular region of the sky. A marked *paucity* of Variable Stars is, however, noticeable in the northern hemisphere in the constellations of the Lynx, Coma Berenices and Canis Venatici, and in the southern constellations, Canis Major, Columba, Pictor, Eridanus, Fornax, Horologium, Grus, Microscopium, Indus, Toucan, Hydrus, and Octans. I notice, however, a tendency to congregate in small subordinate groups. The most remarkable examples of this clustering tendency are as follows:—In and near Corona Borealis, where, in a comparatively small region, there are five Variable Stars; near Cassiopeia's Chair, five; in Cancer, four, comparatively close together; a small region near η Argûs, containing six; and a limited area near the head of Scorpio, which contains no less than 15 small variables. I find that if the whole sky were as rich in variables as this last-named region there would be about 3000 Variable Stars. The number hitherto discovered has not yet reached 300.

A remarkable peculiarity about the Variable and Temporary Stars is, that few of them show any appreciable parallax. For α Cassiopeiæ and α

Herculis a parallax of less than a tenth of a second of arc has been found, but for α Orionis Dr. Elkin finds a negative parallax. These are irregular variables. Observations of Nova Cygni (1876) by Sir Robert Ball failed to show a measurable parallax. For the new star of 1885 in the Andromeda Nebula, Franz also found a negative parallax. A negative parallax implies either that the parallax is too small to be measured, or else that the faint comparison stars are actually nearer to the Earth than their brilliant neighbour. As far as I know, a measurable parallax has not yet been found for any variable star having a *regular* period. Another fact which may perhaps suggest (although it does not *prove*) great distance, is that few of the long period variables rise, even at maximum, above the range of naked eye visibility. As in the case of most rules, however, there are exceptions to this one; Mira Ceti, R. Hydræ, and χ Cygni being the most notable examples.

The evidence in favour of great distance is further strengthened by the fact that none of the Variable Stars have any considerable proper motion. The list of proper motions greater than one second of arc per annum, given in Miss Clarke's *System of the Stars*, does not contain a single known Variable Star. We seem, therefore, to have evidence that the Variable Stars lie at a vast distance from the Earth. How is this peculiarity to be accounted for? The only plausible explanation I can see is that the Sun and

Solar System do not lie in a region of Variable Stars. The periodical increase and decrease of sun-spots may possibly denote some *small* fluctuation of light in our Sun, but seen from the nearest fixed star, this variation of light, if it has any real existence, would be quite imperceptible, and the Solar light would probably seem to be invariable. Our nearest neighbours in the Sidereal System, α Centauri, 61 Cygni, Lalande 21,185, Sirius, etc., appear constant in their light, a proof that in a large region of space surrounding the Sun there is not a single Variable Star.

NOTE.

The following remarks are due to Mr. A. C. Ranyard :—

"In order to exhibit to the eye the grouping of the short period variables mentioned above, I have plotted down the places of the 20 variables of short period referred to on one of Mr. Proctor's pairs of maps, showing the distribution of nebulæ with respect to the Milky Way. I find that 19 out of 20 of these short period variables lie on or near to the region thickly strewn with stars and nebulous matter which we know as the Milky Way. This same region is also rich in red stars and in stars exhibiting bright lines in their spectra, as well as in large and irregular nebulæ, and in star clusters—while the smaller nebulæ seem to avoid it, and to cluster in the poles of the Milky Way. W Virginis, the only one of the short period variables which falls at a considerable distance from the Milky Way, has a comparatively long period of 17·27 days, and its spectrum seems to differ from the spectra of other short period variables.

"The distribution of short period variables with respect to the Milky Way was pointed out some years ago by Prof. E. C. Pickering. Miss A. M. Clerke, in her *System of the Stars*, p. 145, remarks that within the zone of the Milky Way these short period variables display 'an evident disposition towards clustering where the Milky Way divides in Cygnus; the variables follow its southern branch, and they are thickly sown over the whole region from Lyra to Sagittarius.' Indications indeed abound, that the conditions of variability and even of particular kinds of variability are localized in space. Thus in Sagittarius no less than four stars fluctuate in periods of six to seven days.

"The absence of any appreciable parallax in variable stars need not necessarily be due to their great distance. All modern determinations of parallax are based on measures of the distance of the star whose parallax is sought from small stars in its neighbourhood. If variable stars occur in groups or are situated in clusters of small stars, we should expect to find no relative parallax compared with small stars situated at about the same distance from us as the principal star. We have so few stars showing undoubted parallax that it would be unsafe to base any important general conclusion on the fact that no star of the variable class has yet been discovered showing such parallax; but it is more remarkable that no variable star shows any considerable proper motion."

XIV.

THE "DEMON" STAR.

THE fluctuations in the light of the famous variable star Algol, or Beta Persei, were possibly known to the ancient astronomers, as the name Algol, or *al-gûl*, signifies the "demon," and suggests that the old observers of celestial phenomena may have remarked some peculiarity in the light of the star. It should be noted, however, that Al-Sufi, the Persian astronomer, in his *Description of the Heavens*, written in the tenth century, calls the star *râs-al-gûl*, the head of Al-gûl, which seems to imply that the "demon' referred to was the Gorgon, Medusa, whose head appears in the hand of Perseus on the old globes and star maps.

However this may be, the star deserves the name of "demon" from the peculiar character of its variations. Shining with a steady light for about 59 hours, its lustre suddenly begins to diminish, and in about 4½ hours its brilliancy is reduced to about one-third of its normal brightness. It remains at its faintest for about 15 minutes, and then in about 5½ hours recovers its former lustre.

Al-Sufi says nothing about its variability, but remarks: "La 12 est l'étoile brillant d'un éclat rouge et des moindres de la deuxième grandeur," and again: "La brillante étoile rouge qui se trouve dans la tête d'*al-gûl*."[1] Sufi's estimate of its brightness agrees well with modern observations, as, at its normal brilliancy, it was measured 2·31 with the photometer at Harvard Observatory, and 2·40 at Oxford. His description of it as red is remarkable, as most modern observers see it as a white star, or at most of a yellow or *slightly* orange tint. If Sufi's estimate of its colour is as accurate as his descriptions usually are, an extraordinary change of colour has certainly taken place in this curious star, a change all the more interesting from the fact that a change from red to white is also supposed to have taken place in the brilliant Sirius, which has a similar spectrum.

The real discovery of Algol's variability seems to have been made by Montanari in 1669, and confirmed by Maraldi in 1692. The variation of light was also observed by Kirch and Palitzsch. These observers, however, only noticed that the star fluctuated in brightness from about the second to the fourth magnitude, but they did not succeed in determining the law of its variation. This discovery was reserved

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[1] Schjellerup's translation of Al-Sufi's MS. p. 87. Al-Sufi was born A.D. 903, Dec. 7, and died 986, May 25.

for an English astronomer, Goodricke, who in 1782 found that the period from minimum to minimum was about 2 days, 21 hours, that all the fluctuations of light took place in a period of about 7 hours, and that for the remainder of the period the light of the star remained constant at the maximum. Comparing his own observations with one by Flamsteed in 1696 he found the exact period to be 2 days, 20 hours, 48 minutes, 59½ seconds. Goodricke thought "that the cause of this variation could hardly be accounted for otherwise than either by the interposition of a large body revolving round Algol, or some kind of motion of its own, whereby part of its body covered with spots or such-like matter is periodically turned towards the Earth." The correctness of this hypothesis of an eclipsing satellite has been fully confirmed by recent observations with the spectroscope. This will be considered further on.

In recent years the variation of Algol has been carefully studied by Argelander, Schönfeld, Schmidt, and others. Schönfeld found a period of 2 days, 20 hours, 48 minutes, 53·67 seconds, which seemed to show that the period was diminishing in length, a suspicion which has been confirmed by later researches. Schmidt found that the light of Algol was equal to that of Delta Persei about 47 minutes before and after the minimum; to that of Epsilon Persei about 62 minutes before and after the same, and to that of Beta Trianguli 95 minutes before and after the faintest phase. From observations made in the years 1840 to 1875, Schmidt found a period agreeing very closely with that found by Schönfeld. From photometric measures of Algol's light made by Professor Pickering at the Harvard Observatory (U.S.A.), he found that the diminution of light commences about 4 hours, 23 minutes before the minimum, and that the star recovers its normal brightness 5 hours and 37 minutes afterwards, the whole period of light fluctuation being therefore about 10 hours out of the $68\frac{4}{5}$ hours which elapse between minimum and minimum. From these observations it appears that the light remains constant for a period of about $58\frac{4}{5}$ hours, when the fluctuations again re-commence. These curious changes occur with the regularity of clockwork, and the exact day and hour when the star will be at a minimum can be predicted with great accuracy. Prof. Pickering finds that the most rapid diminution of light takes place about 100 minutes before, and the most rapid increase about 100 minutes after, the minimum.

It is stated in several books on astronomy that Algol varies from the second to the fourth magnitude, but this is incorrect. The variation is not so much. At its normal brightness the star is always fainter than an average star of the second magnitude, as was remarked by Al-Sufi, and as modern measures with the photometer clearly show; and at the minimum it is never so faint as an average star of the fourth magnitude. Schönfeld found a variation from 2·2 to 3·7 magnitude, but this is, I think, somewhat too large. My own observations with the naked eye—a method probably as reliable as any other, for small variations of light—show that the total variation very little exceeds one magnitude, and this is confirmed by Prof. Pickering's measures with the photometer. The variation seems to be from magnitude 2·3 to magnitude 3·5. This implies that the star's light at maximum is three times the light at minimum. If we suppose three candles placed side by side, and at such a distance from the eye that their combined light is equal to the normal light of Algol; then if two of them are blown out the remaining single candle will represent the star's light at minimum.

The recorded observations of minima show that the period of variation has been slowly diminishing since Goodricke's time, and from an elaborate investigation of the subject Dr. S. C. Chandler finds that the present period is about 2 days, 20 hours, 48 minutes, 51 seconds. He thinks the period has now nearly reached its minimum value, and that it will soon begin to increase again, the variation in the length of the period being cyclical, and probably due to the orbital revolutions of Algol and its satellite round a third body in a period of about 130 years.

The theory of an eclipsing satellite, originally suggested by Goodricke, was considered mathematically by Prof. Pickering some years since. He showed that a dark satellite of sufficient size revolving in a nearly circular orbit round Algol, and having the plane of its orbit nearly in the line of sight, would explain satisfactorily the observed phenomena within the limits of errors of observation, and he pointed out that it might be possible to determine the orbit of the system by observations with the spectroscope, without any knowledge of the star's distance from the Earth.

To test this theory, Professor Vogel made some measures with the spectroscope in the years 1888 and 1889. His observations seem to show conclusively that the diminution in the light of Algol is really due to a partial eclipse by a large satellite. He found that before the decrease in light commences, Algol is receding from the Earth, and hence the dark satellite is approaching, as it should do when about to transit the disc of its primary. After the minimum is over, Vogel finds that Algol is approaching the Earth and the dark satellite therefore receding. He finds the maximum velocity of recession to be 24½ miles a second, and the maximum velocity of approach 28½ miles per second. The difference between these velocities indicates that the combined system is approaching the Earth at the rate of about two miles a second. Now it is clear that, knowing the velocity in miles per second and the period of revolution—or the star's period of variation from minimum to minimum—we can at once find the circumference of the orbit, and therefore its diameter in miles, without any knowledge of the star's distance from the Earth. Knowing then the dimensions of the orbit, we can easily find the mass of the system in terms of the Sun's mass.[1]

Comparing the light of Algol with that of Sirius, of which the mass and distance have been well determined, and assuming that the two stars have the same density, I find a probable parallax for Algol of 0·14″,[2] representing a distance from the Earth which light would take about 23 years to traverse. Chandler finds a probable parallax of 0·07″, or a light journey of 46 years. The parallax is probably too small to be determined by direct measurement, but an effort should be made in this direction by the photographic method of measuring stellar parallax.

Algol is not the only star which shows this peculiar type of variation. There are other "demon" stars. Ten altogether—including Algol itself—are now known, and probably many others exist which have hitherto escaped detection. The fact of the light variations taking place only during a few hours, while for the rest of the period the star's light is constant, renders their discovery a task of peculiar difficulty. Among the brighter of the Algol variables may be mentioned Lambda Tauri, which varies from magnitude 3·4 to

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[1] See chapter on 'Weighing the Stars.'

[2] *Journal of the British Astronomical Association*, June 1892.

4·2 with a period of a little less than 4 days, and Delta Libræ, which varies from 4·9 to 6·1 in a period of about 2 days, 7 hours, 51 minutes. The others are fainter. A star of this class in the Southern constellation, Antlia, discovered by Mr. Paul in 1888, has the wonderfully short period of 7 hours, 46 minutes, 48 seconds, during which time it varies from magnitude 6·7 to 7·3 and back to 6·7, all the light changes being gone through no less than three times in the 24 hours! The star remains at its maximum brightness for about 4½ hours, and all the light fluctuations take place in a period of about 3 hours, 20 minutes.

In the Algol variables in which the light variation is small—less than one magnitude—it seems probable that the star really consists of two components of equal, or nearly equal, brightness which mutually eclipse each other as they revolve round their common centre of gravity. If this be so, the observed period of variation would be only *half* the period of revolution, as two eclipses would take place in each revolution. On this view of the matter, the period of S Antliæ would be about 15½ hours instead of 7¾. Of the ten known Algol variables, five have a variation of less than one magnitude, so that the stars with bright companions are probably as numerous as those having dark satellites revolving round them.

Herr J. Plassmann has recently announced his observations of a secondary minimum in Algol and Lambda Tauri. This, if true, would suggest that the satellite has some inherent light of its own which is cut off when it passes behind the disc of its primary. The observations of other observers, however, seem to indicate that the light of Algol is constant when at its maximum brightness, and Herr Plassmann seems to be the only observer who has yet noticed a secondary minimum in these stars.

Assuming that the variation of light in these Algol stars is caused by an eclipsing satellite, we seem bound to consider them as not really variable at all, in the true sense of the word. The observed phenomenon is simply due to the occultation of one star by another, which reduces its light in the same way that the solar light is diminished during an annular eclipse of the Sun. They might more correctly be classed as very close binary stars, with very short periods of revolution. Indeed, an examination of photographed stellar spectra has recently revealed the existence of similar double stars with very short periods, but which are not variable in their light because one star does not pass in front of the other. An example of this newly-discovered class of close binary stars is the bright star Beta Aurigæ, for which the observations indicate a period of about four days. The bright star Spica in the Virgin seems to be also closely double with a similar period. Neither of these stars, however, show any variation of light, for the simple reason that the plane of the orbital motion does not pass through the Earth. Viewed from some other point in the universe—from any point in the plane of their orbit—these stars would doubtless appear to an observer as variables of the Algol type. As the variability, therefore, solely depends upon the position of the observer's standpoint, and not from any physical peculiarity in the stars themselves, we must conclude that they are merely very close double stars, having remarkably short periods of revolution.

XV.

COLOURED STARS.

ON a clear night a careful observer will notice a marked difference in the colours of the brighter stars. The brilliant white or bluish-white light of Sirius, Rigel, and Vega contrasts strongly with the yellowish colour of Capella, the deeper yellow or orange of Arcturus, and the ruddy light of Aldebaran and Betelgeuse. These colours are, however, limited to various shades of yellow and red. No star of a *decided* blue or green colour is known, at least among those visible to the naked eye in the Northern Hemisphere. The third magnitude star β Libræ is described by Webb as of a "beautiful pale green hue," but probably such a tint in the light of this star will to most people prove quite imperceptible. Dr. Gould, observing it in the Southern Hemisphere—under of course more favourable conditions—says: "There is a decidedly greenish tinge to the light of β Libræ, although its colour cannot properly be called conspicuous."

Among the ruddy stars visible to the naked eye,

μ Cephei, Herschel's "garnet star," is generally admitted to be the reddest, but it is not sufficiently bright to enable its colour to be well distinguished without the aid of an opera-glass. With such an instrument, however, its reddish hue is striking and beautiful, and very remarkable when compared with other stars in its vicinity. Like so many of the red stars μ Cephei is variable in its light, but it seems to have no regular period, and often remains for many weeks without perceptible change. It may be seen near the zenith in the early evening hours towards the end of October, and when in this position its ruddy colour is very conspicuous.

Among the brightest stars Betelgeuse is perhaps the reddest, and the contrast between its ruddy tint and the white colour of Rigel in the same constellation is very noticeable. Like μ Cephei, Betelgeuse is irregularly variable in its light, but not to such an extent, and, like the "garnet star," it frequently remains for protracted periods nearly constant in brightness. There are other cases of reddish colour among the naked-eye stars. Among these may be mentioned Antares (α Scorpii), Alphard (α Hydræ), noted as red by the Persian astronomer Al-Sufi in the tenth century, and called by the Chinese "The Red Bird"; η and μ Geminorum; μ and ν Ursæ Majoris; δ and λ Draconis; β Ophiuchi; γ Aquilæ, and others in the Southern Hemisphere.

But it is among the stars below the limit of naked-eye vision that we meet with the finest examples of the red stars. Some of these are truly wonderful objects. The small star, No. 592 of Birmingham's Catalogue of Red Stars (No. 713 of Espin's edition), which lies a little south of the 5½ magnitude star 79 Cygni, was described as "splendid red" by Birmingham, "very deep red" by Copeland and Dreyer, and "orange vermilion" by Franks. The star 248 Birmingham, which lies about 5° south of *ν* Hydræ, is another fine specimen. Birmingham described it as "fine red" and "ruby"; Copeland as "brown red"; Dreyer as "copper red"; and Espin as "magnificent blood red." This star is variable in light, as the estimates of magnitude range from 6·7 to below 9. About 3° to the north-east of this remarkable object is another highly-coloured star, known as R Crateris. It is easily found, as it lies in the same telescopic field of view with *α* Crateris, a 4½ magnitude star. Sir John Herschel described it as "scarlet, almost blood-colour; a most intense and curious colour." Birmingham called it "crimson," and Webb "very intense ruby." Observing it with a 3-inch refractor in India in 1875, I noted it as "full scarlet." It varies in light from above the eighth magnitude to below the ninth, and has near it a star of the ninth magnitude of a pale blue tint.

Another very red star is No. 4 of Birmingham's Catalogue, which will be found about 5° north, preceding the great nebula in Andromeda. It is of about the eighth magnitude, and may be well seen with a 3-inch refractor. Krüger describes it as "intensiv roth," Birmingham as "fine red" and "crimson," Franks as "fine colour, almost vermilion," and Espin as "intense red colour, most wonderful."

Another fine object is R Leporis, which forms roughly an equilateral triangle with κ and μ Leporis. This is also variable from 6½ to 8½ magnitude. It was discovered by Hind in 1845, and described by him as "of the most intense crimson, resembling a blood-drop on the background of the sky; as regards depth of colour, no other star visible in these latitudes could be compared with it." Schönfeld called it "intensiv blutroth," but Dunér, observing its spectrum in 1880, gives its colour as a less intense red than that of other stars. Possibly it may vary in colour as well as in light.

The variable star U Cygni, which lies between *o* and ω Cygni, is also very red. Webb described it as showing "one of the loveliest hues in the sky." It varies from about the seventh to 11½ magnitude, with a period of about 461 days.

Another deeply-coloured star is the well-known variable R Leonis. Hind says—"It is one of the most fiery-looking variables on our list—fiery in every stage from maximum to minimum, and is really a fine telescopic object in a dark sky about the time of greatest brilliancy, when its colour forms a striking contrast with the steady white light of the sixth magnitude a little to the north." This latter star is 19 Leonis.

In the Southern Hemisphere there are some fine examples of red stars. ϵ Crucis, one of the stars of the Southern Cross, is very red. μ Muscæ is described by Dr. Gould as of "an intense orange red." δ^2 Gruis is a very reddish star of about the fourth magnitude. π^1 Gruis was observed by Gould as "deep crimson," and forming a striking contrast with its white neighbour π^2 Gruis, which he notes as "conspicuously white." The variable L_2 Puppis is described as "red in all its stages, and remarkably so when faint." Miss Clarke observing—at the Cape of Good Hope—R Doradûs, another southern variable, says—"This extraordinary object strikes the eye with the glare of a stormy sunset,"[1] and with reference to the variable R Sculptoris, described by Gould as "an intense scarlet," she says—"The star glows like a live coal in the field," a description I have found myself very applicable to other small red stars.

An eighth magnitude star about 5° north of β Pictoris, is noted by Sir John Herschel, in his *Cape Observations*, as "vivid sanguine red, like a blood-drop. A superb specimen of its class." With reference to a star of about $8\frac{1}{2}$ magnitude in the field with β Crucis, Herschel says—"The fullest and deepest maroon red; the most intense blood-red

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[1] *Observatory*, December 1888.

of any star I have seen. It is like a drop of blood when contrasted with the whiteness of Beta Crucis."

Of stars of other colours, the asserted green tint of β Libræ has already been referred to. Among the brighter stars of the Southern Hemisphere, θ Eridani, ϵ Pavonis, ν Puppis, and γ Tucanæ are said to be decidedly blue. The wonderful cluster surrounding the star κ Crucis contains several bluish, greenish, and red stars, and is described by Sir John Herschel as resembling "a superb piece of fancy jewellery."

Among the double stars we find many examples of coloured suns. Of these may be mentioned ϵ Boötes, of which the colours are "most beautiful yellow" and "superb blue," according to Secchi; β Cephei, "yellow and violet"; β Cygni, "golden yellow and smalt blue"; γ Delphini, of which I noted the colours in 1874 as "reddish-yellow and greyish-lilac"; α Herculis, "orange and emerald or bluish-green," and described by Admiral Smyth as "a lovely object, one of the finest in the heavens"; ζ Lyræ, "pale yellow and lilac" (Franks); and β Piscis Australis, of which I observed the colours in India as white and reddish-lilac.

Some distant telescopic companions to red stars have been described as blue. This may be in some case due, partly at least, to the effect of contrast. In others the blue colour seems to be real. This has been shown spectroscopically to be the case with the bluish companion of β Cygni.

The physical cause of the difference in the colour of stars is still more or less a matter of mystery. Although we cannot consider it proved that the red stars are cooling and "dying out" suns, as has been suggested, we may, I think, conclude that their temperature, although doubtless very high, must be lower than that of the white stars. We know that a bar of iron when heated to redness is not so hot as when raised to a "white heat," and although the analogy between hot iron and stellar photospheres may not be a perfect one, it seems probable that the higher the temperature of a star, the whiter its colour will be. Most of the white stars, as Sirius, Vega, and those only yellow or slightly coloured, show spectra of Secchi's first and second type, while the great majority of the red stars exhibit banded spectra of the third and fourth types.

To this rule there are, however, like other rules, some notable exceptions. For instance, Aldebaran, α Hydræ, ξ Cygni, and 31 Orionis, although distinctly reddish stars, show well-marked spectra of the second or solar type. On the other hand ρ Ursæ Majoris and ω Virginis, which, according to Dunér, are only slightly yellow, have well-marked spectra of the third type.

An apparent change of colour seems in some cases to be well established. The supposed red colour of Sirius in ancient times is well known. A certain established change is found in the case of the famous variable star Algol, which is distinctly described as red by Al-Sufi in the tenth century. It is now pure white, or nearly so, and this is probably the best attested instance on record of change of colour in a bright star.

Schmidt's Nova Cygni of 1876 was noted as "golden yellow" on the night of its discovery. When it had faded to the eighth magnitude, Dr. Copeland called it "decided red," but when examined at Lord Crawford's observatory in Sept. 1877, its colour was recorded as "faint blue"! The new star in the Andromeda nebula was considered to be yellowish or reddish by most observers when near its maximum, but about a month later its colour was noted as "bluish."

Among the red and variable stars, there are many suspected cases of colour variation. Espin and other observers have noticed that the wonderful variable Mira Ceti is much less red at maximum than at minimum. My own observations confirm this. When at its maximum brightness, Mira does not seem to me a very highly-coloured star, while at one of its minima I noted it as "fiery red." Possibly, however, the great difference between its maximum and minimum brilliancy may have an influence on estimations of its colour. The remarkable variable χ Cygni is said to be "strikingly variable in colour." Espin's observations in different years show it "sometimes quite red, at others only pale orange-red."

The star Birmingham 118 was described by Schjellerup in 1863 as "decided red," but it was found yellow by Secchi in 1868; "bluish" by Birmingham, 1873—1876; "no longer red" by Schjellerup in March 1876; and "white" by Franks in 1885. Espin omits it from his revised edition of Birmingham's Catalogue.

Birmingham 169 was found red by Struve, blue or bluish-white by Birmingham in 1874, and white at Greenwich in the same year. Espin also saw it white in March 1888. The star Birmingham 30, which lies close to ϕ Persei (54 Andromedæ), was described by Schweizer as "étoile rouge présentant un petit disque" in January 1843; Birmingham noted it as "light red" in December 1875; Copeland "deep red" in January 1876; and Dreyer "reddish" in September 1878; but Espin, in November and December 1887, found it "certainly not red, and nothing peculiar in the star's appearance." It might be expected that these curious changes of colour, if real, would be accompanied by corresponding changes in the star's spectrum. Such may be the case, and observations in this direction would probably lead to some interesting results.

There seems to be some law governing the distribution of the coloured stars. The white stars appear to be most numerous, as a rule, in those constellations where bright stars are most abundant, for instance in Orion, Cassiopeia, and Lyra; yellow and orange stars in large and ill-defined constellations such as Cetus, Pisces, Hydra, Virgo, etc. The very reddish stars are most numerous in or near the Milky Way, and one portion of the Galaxy—between Aquila, Lyra, and Cygnus—was termed by Birmingham "the red region in Cygnus."

XVI.

SIRIUS AND ITS SYSTEM.

SIRIUS, or the Dog Star, is the brightest star in the heavens, and from its superior brilliancy has been termed "the monarch of the skies." Measures of its light show that it is about two magnitudes, or over six times brighter than an average first magnitude star like Altair or Spica, and about equal in lustre to three stars like Vega or Capella. Sir John Herschel found the light of Sirius equal to 324 times the light of a star of the sixth magnitude, about the faintest visible to average eyesight. But it is probably over 600 times brighter than a sixth magnitude star. It has been seen in daylight with a telescope of only half an inch in aperture. Some observers have even seen it with the naked eye in sunshine, and it has been observed to cast a shadow like Venus when at its brightest.

The origin of the name Sirius is somewhat doubtful. It may possibly be derived from the Sanscrit word *surya*, the sun. Professor Max Müller thinks that the

Greek word *seirios* comes from the Sanscrit *svar* or *suonasirau*. Sirius is first mentioned as a star by Hesiod, who connects it with the dog days. These, according to Theon of Alexandria, commenced 20 days before Sirius rose with the Sun, and ended 20 days after that date. These so-called dog days commence on July 3, and end on August 11; but, owing to the precession of the equinoxes, Sirius does not now rise with the sun—or heliacally, as it is termed—until August 25, or 14 days after the dog days have ended. The fancied connection of Sirius with the 40 days of summer heat has, therefore, no longer any existence, and must — like many such ideas—be consigned to "the myths of an uncritical period."

Sirius was worshipped by the ancient Egyptians under the names of Sothis (Horus), Anubis, and Thoth, and represented as a man with the head of a dog. Some identify it with the Mazzaroth of Job. It was also supposed to represent Orion's hound, and it may perhaps be identical with the Cerberus of the Greeks.

It seems to be a popular idea that Sirius, now of a brilliant white colour, was a red star in ancient times. But such a remarkable change of hue is not well established. It seems more probable that the idea of change is due to the mistranslation of a word applied to the star by the ancient writers, a word which probably referred to its brightness rather than its colour. Dr.

T. J. J. See has, however, recently collected strong evidence from the classical writers to show that Sirius was really a red star in ancient times. Such a change would, of course, be most interesting and remarkable, indicating, as it would, some wonderful change in the star's chemical constitution.

Like many other stars, Sirius has a considerable "proper motion" across the face of the sky, amounting to about 1·3″ of arc per annum. Some irregularities in this proper motion led the astronomers Bessel, Peters, and Safford to the conclusion that the motion of Sirius was disturbed by the attraction of an invisible close companion revolving round it. From the recorded observations Peters computed an orbit for the supposed companion, and found a period of about 50 years. Safford also investigated the problem, and announced in 1861 the probable position of the invisible companion. About four months after the publication of Safford's results, Mr. Alvan Clark, the famous American optician, observing with a telescope of 18½ inches aperture, detected a small star near Sirius, the position of which agreed closely with that of Safford's hypothetical companion. Here was a case somewhat similar to the discovery of the planet Neptune—the prediction, by mathematical analysis, of the existence of a celestial body previously unknown to astronomers. Numerous observations of this small star have been made since its discovery, and there is now no doubt that it is revolving round its brilliant primary. That the observed irregularities in the proper motion of Sirius are wholly due to the influence of this companion seems, however, to be still an open question. Several orbits have been computed, most of which assign a period of 49 or 50 years; but an orbit recently computed by the present writer gives a period of about 58½ years, and Howard finds a period of 57 years. Burnham, however, thinks that 53 years is probably nearer the truth. As the companion has now approached Sirius so closely as to be invisible with even the giant telescope of the Lick Observatory, some years must elapse before the exact length of the period can be definitely settled.

The great brilliancy of Sirius has naturally suggested proximity to the Earth, and modern measures of its distance have confirmed the accuracy of this idea. The most reliable determinations of its parallax (or the angle subtended by the radius of the Earth's orbit at the place of the star) make it about four-tenths of a second of arc, and places it about fourth in order of distance from the Earth.[1] Assuming a parallax of 0·39 of a second (about a mean of the results found by

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[1] The three nearest stars are: *α* Centauri (parallax 0·76 of a second), 61 Cygni (0·45″), and Lalande 21,185, for which Kapteyn found a parallax of 0·434″, and Winnecke 0·5″. For the star *η* Herculis a parallax of 0·40″ was found by Belopolsky and Wagner; but this does not seem to have been confirmed by any other astronomer.

Drs. Elkin and Gill), the distance of Sirius would be 528,884 times the Sun's distance from the Earth, a distance which light would take about 8⅓ years to traverse.

Knowing the distance of Sirius from the Earth, and its annual proper motion, it is easy to calculate its actual velocity in a direction at right angles to the line of sight. This comes out about ten miles a second. The spectroscope shows that Sirius has also a motion in the line of sight, and hence its real velocity through space must be greater than that indicated by its proper motion. In the year 1864 observations by Dr. Huggins showed that Sirius was receding from the Earth at the rate of 29 miles a second. Some years afterwards careful measures of the star's spectrum showed that this motion had ceased; subsequent measures showed that the motion was reversed, and recent observations by Dr. Vogel indicate unmistakably that the motion has now been changed into a motion of approach! It seems difficult to understand how this curious change in the direction of the star's motion can be accounted for otherwise than by orbital movement; in the same way that the planet Venus is sometimes approaching the Earth and sometimes receding from it, owing to its orbital motion round the Sun. The motion may possibly be due to the existence of some invisible close companion.

Placed at the distance of Sirius, the Sun would, I find, be reduced to a star of only the third magnitude, or about four magnitudes brighter than Sirius appears to us. This indicates that Sirius is about 40 times brighter than the Sun would be in the same position, and would imply that Sirius is a far more massive sun than ours. If we assume the same intrinsic brilliancy of surface and the same density for both bodies, the above result would make the diameter of Sirius 6·32 times the Sun's diameter, and its mass no less than 253 times the mass of the Sun. As, however, the intrinsic brightness of the surface of Sirius and its density, or specific gravity, may differ widely from those of the Sun, these calculations are of course open to much uncertainty. The light of Sirius, analyzed by the spectroscope, differs considerably from the solar light, and the strong development of the hydrogen lines in the star's spectrum denotes that Sirius is, in its chemical constitution, not comparable with our Sun. It may possibly be very much hotter, and therefore smaller in diameter and mass than the figures given above would indicate. Fortunately we can find the mass of a binary or revolving double star by another and more certain method. Knowing the orbit of the star and its distance from the Earth, we can calculate the combined mass of the components in terms of the Sun's mass. Making the necessary computations for Sirius, I find that the combined mass of Sirius and its companion is a little over three times the mass of the Sun, and the mean distance between them 22 times the Sun's distance from the Earth, or a little more than the distance of the planet Uranus from the Sun. This result—recently confirmed by Dr. Auwer's calculations—would imply that Sirius is intrinsically a much brighter sun—surface for surface—than ours, and that "the monarch of the skies" is a "giant" only in appearance; the greater brightness of its surface and its comparative proximity to the Earth accounting for its great apparent brilliancy.

The companion of Sirius has been estimated as of the tenth magnitude. This would imply that the light of Sirius is about 25,000 times the light of the small star. If, therefore, the two bodies were of the same density and intrinsic brightness, the mass of Sirius would be about 4,000,000 times as great as the mass of the companion. But Dr. Auwers concludes, from his researches on the proper motion of Sirius, that the companion is about one-half the mass of the primary, and equal in mass to our Sun! It must, therefore, be nearly a dark body. It has been suggested that the companion may possibly shine by reflected light from Sirius, in the same way that the planets of the Solar System shine by reflected light from the Sun. Some calculations which I have recently made show, however, that this hypothesis is wholly untenable.[1] Assuming, with Auwers, that the mass and diameter of the companion are equal to those of the Sun, I find that the companion would, if illuminated solely by reflected light from Sirius, shine as a star of only 16½ magnitude. A star of this magnitude—about the faintest visible in the great Lick telescope—placed close to a brilliant star like Sirius would, even when most favourably situated, be utterly invisible in our largest telescopes. If its mass is much less than one-half that of Sirius—as its faintness would seem to suggest—it is possibly a comparatively small body, and the reflected light from its primary would be proportionately less. It seems clear, therefore, that the companion must shine with some inherent light of its own, otherwise it could not possibly be so bright as the tenth magnitude. It is probably a sun of small luminosity revolving round Sirius in the same way that the companions to other binary stars revolve round their primary. The disparity in brightness is, however, remarkable, no other binary star showing so great a difference in the brilliancy of the components.

As I have said above, the Sun, if placed at the distance of Sirius, would shine as a star of the third magnitude. There is, therefore, a difference of seven stellar magnitudes between the light of the Sun and

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[1] *Journal of the British Astronomical Association*, March 1891.

that of the Sirian satellite. This implies that the light emitted by the Sun is 631 times greater than that radiated by the companion of Sirius. If of the same intrinsic brightness of surface, the latter would, therefore, have a diameter about $\frac{1}{25}$th of the Sun's diameter, or 34,000 miles. But if of the same mass as the Sun, its density with this small diameter would be enormous—in fact, vastly greater than we can imagine possible for any body large or small. Indeed, if we suppose its diameter to be one-half that of the Sun, its density would be 11·52 (1·44 × 8), or about equal in density to lead, and it seems very improbable that a self-luminous body could have so high a density as this. We must conclude, therefore, that the satellite of Sirius is a comparatively large body having a small intrinsic brilliancy of surface—possibly a cooling body verging towards the utter extinction of its light. If this be so, it will probably, in the course of ages, disappear altogether from telescopic vision, and its continued existence will only be known by its influence on the motion of Sirius.

If there are any planets revolving round Sirius they will probably remain for ever unknown to us. A planet comparable with Jupiter in size would be utterly invisible in the giant telescope of the Lick Observatory, or even with an instrument very much larger. I am disposed, however, to think that these binary stars may perhaps form exceptions to the general rule of stellar systems, and that single stars, like our Sun, more probably form the centres of planetary systems like our own. Or possibly the reverse of this may be true, the single stars forming the exceptions, and binary stars the rule. In either case we may conclude, I think, judging from the analogy of our Sun, that single stars are more likely to have planets revolving round them.

XVII.

DARKENINGS OF THE SUN.

THERE are many cases recorded in history of the Sun having been remarkably darkened, and the daylight obscured for periods of varying duration. Calculation shows that some of these were undoubtedly due to total eclipses of the Sun, but others cannot be so easily explained.

Plutarch speaks of the paleness of the Sun during the year 44 B.C. This was about the time of the assassination of Julius Cæsar, and calculation proves that no total eclipse of the Sun occurred in that year.

The darkness recorded at the Crucifixion of our Saviour was certainly not due to an eclipse of the Sun, as has been suggested by some ignorant sceptics. For the darkness occurred at the Paschal *full moon*, and lasted three hours, facts quite irreconcilable with the conditions of a solar eclipse. The darkness recorded in the Gospels is also mentioned by contemporary historians.

In the year A.D. 192 it is said that "stars were seen in the daytime," but there was certainly no total eclipse of the Sun that year.

Again, it is recorded that when the famous Alaric appeared before the walls of Rome (A.D. 409) a darkness set in so great that stars were seen in the daytime. Shortly before the capture of the city (August 410) there was a partial eclipse of the Sun visible at Rome (June 18), but the central line of the eclipse—which was an annular one—passed considerably south of Rome.

In the year 536 A.D. the Sun's light is said to have been greatly diminished, and to have remained so for about fourteen months! In 626 and 627 the Sun is said to have lost half its light! There seem to have been no great solar eclipses in either of these years.

According to Schnurrer, a remarkable Sun darkening occurred in September 1091, which lasted three hours. There was no total eclipse of the Sun at this time; but a darkening recorded by the same writer in June 1191 may be explained by a great solar eclipse—mentioned by English writers—which took place on June 23 of that year. The eclipse was, however, only an annular one, so that the darkness could not have been great. This fact tends to show that the descriptions given of these phenomena by the early writers are probably much exaggerated.

In the Chinese Annals "a great diminution of light" is recorded on July 8, 1103, which cannot be accounted for by an eclipse. The same remark applies to a darkening on February 12, 1106, mentioned by Erman as having been accompanied by meteors. The allusion to meteors is very significant, suggesting the probable interposition of a meteoric swarm between the Sun and Earth. On February 4 of the same year a great comet was seen close to the Sun in full daylight. It has been thought probable that this comet is identical with the great "September comet" of 1882. Possibly a swarm of meteors was travelling in the wake of the comet of 1106, and passed between the Sun and Earth, or perhaps actually collided with the Earth as the Leonids do.

A Spanish writer relates that on the last day of February 1206 there was total darkness for six hours. With reference to this startling statement, it seems worth remarking that an eclipse of the Sun is recorded by several writers on February 28, 1207, so that if we suppose the writer to have made a mistake of one year, and if for "six hours" we read six minutes, the occurrence might be explained.

In April 1547 the Sun's light is said to have been so diminished that for three days stars were seen in the daytime, the Sun appearing "as though suffused with blood." There was no total eclipse in this year.

It seems worthy of notice that some of the dates mentioned above fall close to calculated epochs of Sun-spot maxima. Although in recent years there has been no extraordinary development of Sun-spots at the epoch of maxima, it is not altogether impossible that in former times these spots may have occasionally increased to such an extent, both in number and size, as to have perceptibly darkened the Sun's light. A more probable explanation, however, seems to be the passing of a meteoric or nebulous cloud between the Sun and Earth. The most recent instance of Sun-darkening recorded in this country occurred on May 22, 1870, when the Sun's light was observed to be considerably reduced in a cloudless sky in the west of Ireland; at Greenwich on the 23rd, and on the same day, but at a later hour, in north-eastern France —" a progressive manifestation that seems to accord well with the hypothesis of moving nebulous matter." A similar phenomenon was observed in New England on September 6, 1881.

XVIII.

THE NUMBER AND DISTANCE OF THE VISIBLE STARS.

THAT the visible stars are not uniformly scattered through space, and are not of uniform size and intrinsic brightness, is clearly shown by modern researches. Measures of stellar parallax show that some small stars (that is, faint stars) are actually nearer to our system than many of the brighter stars, while the period of revolution of some binary stars show that their mass is relatively small compared with the brilliancy of their luminous surfaces. We may, however, perhaps assume that the stars, out to some limited distance in space, are scattered with some rough approach to uniformity. We can at least calculate the average distance between the neighbouring stars, which would give a certain number of stars in a sphere of given radius. This is easily done by supposing the stars placed at the angular points of a tetrahedron. A tetrahedron is a solid figure bounded by four equal surfaces, each surface being an equilateral triangle. It is clear that in such a solid, each of the angular points is equidistant from the other three angular points of the figure, and that stars so placed in space would be "uniformly distributed" through the space containing them.

With this arrangement the number of stars contained in a given sphere may be easily calculated, assuming a certain distance between each pair of stars; but the calculation will only apply to a sphere of a radius very large in comparison with the distance between the stars distributed through it. If we suppose the distance between the stars equal to the radius of the sphere, the calculation gives, I find, 35 equi-distant stars in the sphere. This number is evidently too great, as the number of stars which can be placed on the surface of a sphere of given radius, equi-distant from each other and from the centre of the sphere, is only 12. The difference is clearly due to the fact, that in this case the volume of the tetrahedron is so large in proportion to the volume of the sphere that the latter cannot be accurately divided into tetrahedrons. In the case, however, of a sphere whose volume is very large in proportion to the volume of the tetrahedron formed by four adjacent stars, the calculation will be approximately correct. Let us call the distance between two adjacent stars the *unit distance*.

Now considering *α* Centauri, for which the largest parallax has been found (about 0·76″), it is obvious at once that this star cannot be at the "unit distance" from the Sun. For if α Centauri was at the "unit distance," we might expect to find some ten or eleven other stars at a similar distance from the Earth. Such is, however, probably not the case, and we may therefore conclude that this star is comparatively near our system, and forms an exception to the general rule of stellar distance.

To make this point clearer, let us see what number of stars should be visible to the naked eye—say to the sixth magnitude inclusive—on the assumption that the distance between the Sun and α Centauri forms the "unit distance" between two stars of the visible sidereal system, or at least that portion of the system which is visible without a telescope. To make this calculation, it will of course be necessary to assume some average distance for stars of the sixth magnitude based on actual measurement. Now Peters found an average parallax of 0·102″ for stars of the first magnitude, Gyldén found 0·083″, and Elkin 0·089″. These results are fairly accordant, and we may assume the mean of these values, or 0·09″, as the mean parallax of an average star of the first magnitude.

With a "light ratio" of 2·512, the light of a first magnitude star is 100 times the light of a sixth, and hence—as light varies inversely as the square of the distance—the distance of an average sixth magnitude star would be ten times that of a first. Its parallax would therefore be 0·009″. Hence the radius of the sphere containing all stars to the sixth magnitude inclusive would be 0·76 divided by 0·009, or 84·4 times the distance of α Centauri. From this I find that the number of stars contained in the sphere would be 21,372,000, a number enormously greater than the known number of stars to the sixth magnitude.

This result shows that, on the hypothesis of uniform distribution, α Centauri cannot lie at the "unit distance" from the Sun, and that it is probably an exceptionally near star. The same may be said of 61 Cygni, Sirius, and other stars with a large parallax. But the above result also leads us to doubt whether the mean parallax of sixth magnitude stars is so small as 0·009″. I find that the Sun placed at the distance indicated by this parallax would shine only as a star of the eleventh magnitude[1]; that is, a sixth magnitude star would be five magnitudes, or 100 times brighter than the Sun placed in the same position. If of the same intrinsic brilliancy of surface, this would imply that an average sixth magnitude star has ten times the diameter of the Sun, and therefore 1000 times its volume! Some sixth magnitude stars may possibly exceed our Sun in size, but that the *average* volume of these small stars is 1000 times that of the Sun seems wholly improbable. Certainly the calculated masses of those

[1] See chapter on 'The Sun among his Peers.'

binary stars of which the distance from the Earth has been determined, do not give any grounds for supposing that such enormous bodies exist among stars of the sixth magnitude.

Assuming, however, that the parallax of a first magnitude star is 0·09″, and that of a sixth magnitude star is one-tenth of this, or 0·009″, let us see what number of stars should be visible to the sixth magnitude. As already stated, the number of equidistant stars which can be placed on the surface of a sphere of unit radius is 12. Hence on the surface of a sphere of double this radius, four times the number, or 48 equi-distant stars may be placed; on a sphere of three times the radius, nine times the number, and so on. Now the sum of ten terms of this series 1^2, 2^2, 3^2, etc., is 385, and as the twelve stars which may be placed on the first sphere nearly represent the number of stars of the first magnitude and brighter visible in both hemispheres, we have the total number of stars to the sixth magnitude inclusive 385 × 12, or 4620.

Now the number of stars to the sixth magnitude in both hemispheres, as observed by Heis and Gould, is 4181, and the number contained in the *Harvard Photometry*, and the *Uranometria Argentina* is 3735, so that the number of stars computed on the above principle does not differ widely from the number actually observed.

Let us see now what the unit parallax would be for the observed number of stars to the sixth magnitude, assuming a parallax of 0·009″ for stars of this magnitude. Taking the number as 3735, I find by the tetrahedron hypothesis that the parallax of the star at "unit distance," that is the mean parallax of the nearest stars to the Earth, would be 0·042″. Excluding stars with a large parallax, this may not be far from the truth. I find that in 31 binary stars brighter than the sixth magnitude (and for which a parallax has not yet been determined), the average "hypothetical parallax"—or the parallax on the assumption that the mass of the system is equal to the mass of the Sun—is 0·068″. If we assume the mass of each of these systems to be, on an average, twice the Sun's mass, we must divide this by the cube root of 2. This gives for the average parallax 0·054″, which does not differ widely from the unit parallax found above for stars of the sixth magnitude.

But we are still confronted with the difficulty that with a parallax of only 0·009″, stars of the sixth magnitude would be on an average considerably larger than the Sun. The same remark applies to stars of the sixteenth magnitude, for which the parallax would be only 0·00009″. Placed at this vast distance, the Sun would, I find, be reduced to a star of magnitude 21·3, and would, therefore, be utterly invisible in the largest telescopes yet constructed. It would be over 100 times fainter than a star of the sixteenth magnitude!

To reduce the Sun to a star of the sixth magnitude, it should be placed at a distance corresponding to a parallax of 0·1″. Unless, therefore, stars of the sixth magnitude are, on the average, considerably larger than our Sun, we seem justified in thinking that their average parallax is not less than one-tenth of a second. But, as has been stated, this is about the average parallax of stars of the first magnitude, and it is difficult to believe that these bright stars are as far from the Earth as the faint stars which lie near the limit of naked-eye vision. There seems, however, no escape from the conclusion that sixth magnitude stars are probably nearer to us than their brightness might lead us to suppose, and to explain the difficulty with reference to the brighter stars, we may perhaps assume that their brilliancy is due rather to their great size than proximity to our system. From the small parallax found for Arcturus, Vega, Capella, Canopus, and other bright stars, we have good reason to think that these stars are vastly larger than our Sun.[1] Spectroscopic observations of ζ Ursæ Majoris indicate that this second magnitude star has a mass about 40 times the mass of the Sun, and possibly other bright stars may have similarly large masses. Sirius and α Centauri, however, form notable exceptions to this rule.

Assuming an average parallax of one-tenth of a second for stars of the sixth magnitude, the parallax

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[1] See chapter on 'The Sun among his Peers.'

of a star at the "unit distance" from the Sun would be 0·47″. This is about the parallax found for 61 Cygni, and does not much exceed that of Sirius. There are several other stars with a parallax of somewhat similar amount, and possibly there may be others hitherto undetected.

With a parallax of 0·1″ for a sixth magnitude star, the parallax of an eleventh magnitude would be 0·01″, and that of a sixteenth magnitude 0·001″. Now with the unit distance corresponding to a parallax of 0·47″, I find that the number of equi-distant stars contained in a sphere of radius equal to the distance of a sixteenth magnitude star would be 3,690,700,000, a number about 36 times greater than the number of the visible stars, generally assumed at 100,000,000. According to Dr. Gould's formula, the number of stars to the sixteenth magnitude would be 3,024,057,632, or about 30 times the number actually visible.

Probably, however, we are not justified in assuming a uniform distribution of stars to the sixteenth magnitude, most of these faint stars belonging to the Milky Way. Professor Celoria found that, near the pole of the Galaxy, a small telescope, which showed stars to only the eleventh magnitude, revealed as many stars as Herschel's large gauging telescope of 18·8 inches aperture. Here, therefore, we seem to have the extension of our sidereal system limited to the distance of eleventh magnitude stars. Let us now assume a uniform distribution of stars to the eleventh magnitude. With a parallax of 0·01″, and a unit parallax of 0·47″, I find the number of stars 3,690,700. The number by Gould's formula is 3,283,876. Both results are largely in excess of the number actually visible, and show, I think, that there is probably a "thinning out" of the stars before we reach the eleventh magnitude distance, at least in extra Galactic regions. If we suppose that of the 100,000,000 of visible stars, 50,000,000 are scattered uniformly through a sphere having a radius equal to the distance assumed for stars of the eleventh magnitude—the remaining 50,000,000 being included in the Milky Way—we have an average "unit parallax" (that is, the parallax of a star as seen from its nearest neighbour) for these 50,000,000, of about 0·11″, which seems to indicate a "thinning out" of the stars towards the boundaries of our visible sidereal system. If this be so, we may conclude that the stars with a larger parallax than 0·11″ are exceptions to the general rule of stellar distribution, and form, perhaps, comparatively near neighbours of our Sun. These near stars, seen from the outskirts of the visible universe, may perhaps form a small open cluster. Thus the parallax of *a* Centauri being 0·76″, the Sun and *a* Centauri, seen from a sixteenth magnitude star—equally distant from both—would appear as two faint stars about 4½′ of arc apart.

The above results are of course based on the assumption that the faint telescopic stars lie at a distance indicated by their brightness. Such, however, may not be the case. Many of these small stars may be in reality absolutely small. The apparently close connection between bright and faint stars, as shown by photographs of the Milky Way near *α* Cygni and *α* Crucis, suggests that bright naked-eye stars and faint telescopic objects may, in some cases at least, lie in the same region of space. If this be so, the difference in the size of these distant suns must be enormous, and would lead to the conclusion that possibly the Milky Way may not lie so far from our system as has been generally supposed. If, as has been suggested, there is any extinction of light in the ether—which is, however, very doubtful—the faintest stars cannot be placed at a distance corresponding to their relative brightness.

XIX.

SWARMS OF SUNS.

AMONG the so-called nebulæ are many objects which, when examined with telescopes of adequate power, are seen to be resolved into myriads of small stars. Their comparative isolation from surrounding objects impresses us forcibly with the idea that they form, as it were, families of stars connected by some physical bond of union. Of these clusters, as they are called, we have naked-eye examples in the Pleiades, and the "Bee Hive" in Cancer. Others may be partially seen with a good opera-glass or binocular, but most of them require telescopes of considerable power to view them to advantage. They are of various forms and of all degrees of condensation. Some are comparatively large and irregular, others small and compressed, with the component stars densely crowded. Many are of such uniform shape as to have received the name of globular clusters. These have been aptly termed "balls of stars," and are among the most interesting objects in the stellar heavens. The most remarkable example of this class visible in the Northern Hemisphere is that known as 13 Messier. It lies between the tolerably bright stars Zeta and Eta Herculis, nearer the latter star. It may be seen with an opera-glass as a hazy-looking star of about the sixth magnitude, with a star on each side of it. Examined with a powerful telescope it is resolved into numerous small stars. Sir William Herschel estimated them at 14,000, but the real number is probably much less. Assuming the average magnitude of the components at twelve and a half, I find that an aggregation of 14,000 stars of this brightness would shine as a star of about the second magnitude, or a little fainter. Examining this object with his giant telescope, Lord Rosse noticed three dark rifts radiating from the centre. These were afterwards seen by Buffham, with a 9-inch reflector, and also by Webb. They were also observed at the Ann Arbor Observatory (U. S. A.) in April 1887, by Professor Harrington and Mr. Schaeberle, using telescopes of 6 and 12 inches aperture. Professor Harrington, comparing his drawing with that of Lord Rosse, thinks that the rifts "have shifted their position slightly in the 50 or more years which have elapsed since the first drawing was made." This seems, however, very improbable. The suspected change may be simply due to difference in the methods of delineation, and in the relative sharpness of the observer's eyesight. This cluster has been successfully photographed at the Paris Observatory, and by Mr. Roberts at Liverpool. In these photographs the dark rifts are traceable to some extent, but owing perhaps to over-exposure of the central portion of the cluster they are not so distinct as in the drawings referred to. Examined with the spectroscope, Dr. Huggins finds the spectrum continuous, but deficient at the red end, like the great nebula in Andromeda. Mrs. Huggins has, however, pointed out that this apparent suppression of red rays is simply due to the faintness of light in these objects.[1] Spectroscopic evidence is, however, hardly necessary to prove that the Hercules cluster consists of small stars, as these are distinctly seen as points of light with telescopes of moderate power, and with the great Lick telescope the component stars are visible even in the central portion of the cluster.

Another object of the globular class, but less resolvable, is that known as 92 Messier, which lies between the stars Eta and Iota, in Hercules, nearer the latter. Sir William Herschel's telescopes showed it as seven or eight minutes of arc in diameter. It is considerably brighter at the centre. The larger components are easily visible in moderate-sized telescopes, but even Lord Rosse's giant instrument failed to resolve the central blaze. There is no doubt, however, that it consists wholly of small stars, as the unerring eye of the spectroscope shows a stellar

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[1] *The Observatory*, December 1890.

spectrum, similar to that of the neighbouring 13 Messier.

Another fine example of the globular class is 5 Messier, which lies closely north, preceding the fifth magnitude star, 5 Serpentis. It is considerably compressed at the centre. Sir W. Herschel counted 200 stars, but failed to resolve the central nebulosity. Messier, its discoverer, found it visible with a telescope only one foot long.

Another fine object is 3 Messier, in Boötes. Admiral Smyth describes it as "a brilliant and beautiful globular aggregation of not less than 1000 small stars." It is beyond the power of small telescopes, but it was resolved by Buffham, even in the centre, with a 9-inch reflector.

Numerous fine examples of the globular class are found in the Southern Hemisphere, which indeed seems to be richer in these marvellous objects than the northern sky. Of these the most interesting are those known as Omega Centauri, and 47 Toucani. Omega Centauri from its great apparent size—about two-thirds of the Moon's diameter—and its visibility to the naked eye, may perhaps be considered as the most remarkable object of its kind in the heavens. It shines as a hazy star of the fourth magnitude, and I have often so seen it in the Punjab sky. Its large size and globular form are clearly visible in a binocular field-glass, but of course its component stars are far beyond the reach of such an

THE STAR CLUSTER ω CENTAURI.

From a Photograph taken by D. GILL, *at the Royal Observatory, Cape of Good Hope, on May 25th,* 1892.

instrument. Sir John Herschel, observing it with his large telescope at the Cape of Good Hope, found it "a truly astonishing object. All clearly resolved into stars of two magnitudes, viz. thirteen and fifteen, the larger lying in lines and ridges over the smaller; . . . the larger form rings like lace-work on it." I have shown elsewhere[1] that if we take the average magnitude of the components at thirteen and a half the apparent brightness of the cluster would imply that it contains about 15,000 stars.

Another wonderful cluster is that known as 47 Toucani, which lies close to the smaller Magellanic cloud. It is smaller in apparent size than Omega Centauri, but Dr. Gould, observing it at Cordoba, speaks of it as "one of the most impressive and perhaps the grandest of its kind in either hemisphere," and he estimates its magnitude at four and a half, as seen with the naked eye. It is thus described by Sir John Herschel—"A most magnificent globular cluster. It fills the field with its outskirts, but within its more compressed part I can insulate a tolerably defined, circular space, of 90″ diameter, wherein the compression is much more decided, and the stars seem to run together, and this part, I think, has a pale pinkish or rose colour . . .

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[1] *Planetary and Stellar Studies*, p. 191. On a photograph recently taken at Arequipa, Peru, 6389 stars have been actually counted, but the enumerator, Mr. Baily, considers that it includes a much larger number.

which contrasts, evidently, with the white light of the rest. The stars are equal, fourteen magnitude immensely numerous and compressed. . . . Condensation in three distinct stages. . . . A stupendous object." Sir John Herschel's drawing of this cluster reminds one of a swarm of bees, and perhaps suggested to Tennyson the lines,

"Clusters and beds of worlds, and bee-like swarms
Of suns and starry streams."

There are other interesting specimens of the globular class in the Southern Hemisphere, but not of such large apparent dimensions as those already described. Of these may be mentioned 22 Messier, which lies about midway between the stars Mu and Sigma Sagittarii. It is described by Sir John Herschel as a fine globular cluster, with stars of two magnitudes, namely, eleven or twelve, and fifteen or sixteen, the larger being visibly reddish, and he suggested that it consists of "two layers, or one shell over another." Owing to the comparative brightness of the larger components, this cluster forms a good object for small telescopes. I saw the brighter stars well with a 3-inch refractor in the Punjab sky, but, of course, the greater portion of the cluster has a nebulous appearance in a telescope of this size.

Between Alpha and Beta Scorpii there is a condensed globular cluster. With small telescopes it very much resembles a telescopic comet, but with larger instruments its true character is revealed. Sir William Herschel considered it "the richest and most condensed mass of stars in the firmament." In May 1860, a "temporary star" of the seventh magnitude suddenly appeared in the centre, almost blotting out the cluster by its superior light. The star faded away before the end of June of the same year, and has not been seen with any certainty since. It has been suggested that this temporary star lay *between* the cluster and the Earth, but it seems to me much more probable that the outburst took place *in* the cluster itself, and that it was possibly caused by a collision between two of the component stars, or by a swarm of meteors rushing with a high velocity through the cluster.

The beauty and sublimity of the spectacle presented by these globular clusters, when viewed with a powerful telescope, is such as cannot be adequately described, and it has been said that when seen for the first time, "few can refrain from a shout of rapture." The component stars, although distinctly visible as points of light, defy all attempts at counting them, and seem literally innumerable. Placed like a mass of glittering diamond-dust on the dark background of the heavens, they impress us forcibly with the idea that if each of these lucid points is a sun, the thousands which seem massed together in so small a space must be in reality either relatively close and individually small, or else the system of suns must be placed at a distance almost approaching the infinite. The former hypothesis is perhaps the more probable, although it is not easy to imagine, on mechanical principles, how an immense assembly of bodies filling a globular space can exist in that condition without interfering with each other's motions. At rest they cannot be, as their mutual attractions would soon produce a velocity in each member of the system. They must therefore be in motion, each star, perhaps, describing its own ellipse round the centre of gravity of the whole mass, which is probably situated near the centre of the sphere.

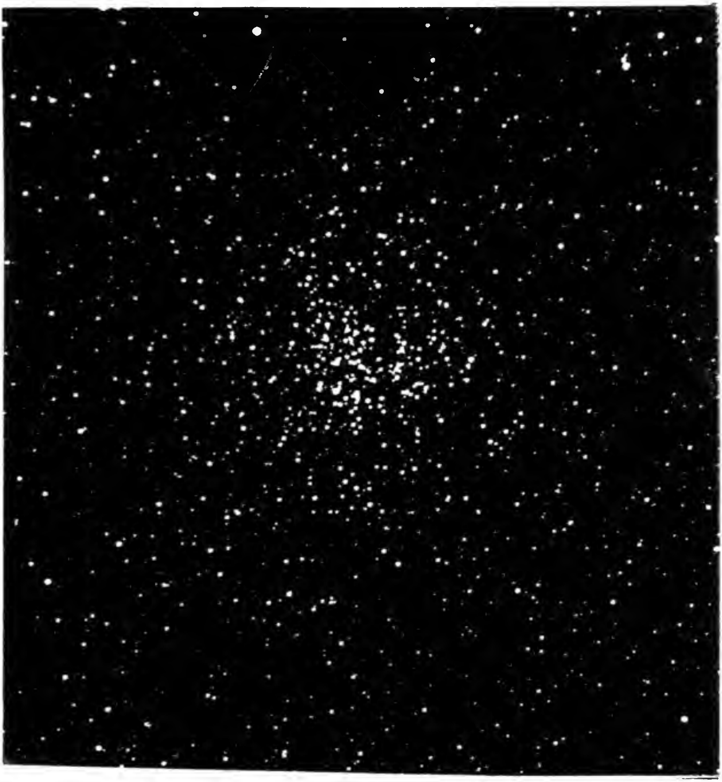
The distance of these globular clusters from the Earth is, however, certainly very great. Attempts to accurately determine their position in space have not been attended with success. As the component stars are at practically the same distance from the eye, we have no comparison stars to measure from, and their exact distance therefore remains unknown. We may, however, estimate their probable distance with some show of plausibility. We may assume that the stars of the Hercules cluster would, if concentrated in a point, shine as a star of about the fourth magnitude. As the components are of the twelfth and thirteenth magnitudes, this would imply that the cluster consists of about 2500 stars. Now, assuming the average distance found by Dr. Elkin for stars of the first magnitude (about 36 years of light travel), I find that a star of the fourth magnitude would be at such a distance from the Earth that its parallax, as it is called, would be about one-fiftieth of a second of arc, a distance which light, with its velocity of 186,000 miles a second, would take 148 years to traverse! Now, neglecting the outliers of the cluster, we may take the apparent diameter of the more condensed part at 5′ of arc (about one-sixth of the Moon's diameter). This, with the assumed distance, would denote that the real diameter of the cluster is about 15,000 times the Sun's distance from the Earth, which would give a distance between each component of about 890 times the Sun's distance, or about 29 times the distance of Neptune from the Sun. Hence, although apparently crowded together, the constituent stars may possibly be separated by immense intervals. Placed at the vast distance assumed for the cluster, our Sun would appear as a small star of between the ninth and tenth magnitudes. Each component of the cluster shines therefore with one-sixteenth of the solar light, and, if of the same density, would have one-sixty-fourth of the Sun's mass. The total mass of the cluster would therefore be equal to about 40 suns. With the data assumed, we may therefore conclude that the components of the Hercules cluster are suns of comparatively small size, separated by considerable distances, but apparently massed together by the effect of distance.

Among less condensed star clusters there are many interesting objects. The Pleiades have been already referred to. On a photograph of this remarkable group, taken at the Paris Observatory, over 2000 stars can be counted of all degrees of brilliancy, from those visible without optical aid, down to points of light so faint as to be invisible to the eye in the telescope with which they were photographed. Here we have a cluster of probably larger size than that in Hercules, possibly at a greater distance from the Earth, and with its larger components of considerably greater mass than that of our Sun.

Near the bright star Pollux, I see a small cluster of stars of about the seventh and eighth magnitudes, which, with a binocular field-glass, very much resembles the Pleiades as seen with the naked eye. A similar cluster (known as 39 Messier) may be seen near the star π' Cygni.

The well-known double cluster, χ Persei, may be also seen with an opera-glass, but a telescope is necessary to show the component stars to advantage, and the larger the telescope the greater the number of faint stars visible in these wonderful objects. They have been well photographed at the Paris Observatory, and on the photograph the clusters are clearly resolved (at least on the paper print in my possession), with no trace of outstanding nebulosity, suggesting that the component stars are probably at nearly the same distance from the earth.

The cluster known as 35 Messier, a little north of the star η Geminorum, is visible in an opera-



N

M 37 AURIGÆ $5^h\ 45^m + 32° \ 31'$.

February 8th, 1893. 90 *minutes exposure.*

glass, but a small telescope is required to see the component stars. A beautiful photograph of this cluster has also been obtained at the Paris Observatory. A well-marked clustering tendency is visible among the brighter stars of the group, two, three, four, and sometimes five stars being grouped together in subordinate collections. Admiral Smyth says—" It presents a gorgeous field of stars from the ninth to the sixteenth magnitude, but with the centre of the mass less rich than the rest. From the small stars being inclined to form curves of three or four, and often with a large one at the root of the curve, it somewhat reminds one of the bursting of a sky-rocket." This tendency to " stream " formation in the components of star clusters is also well marked in a photograph of the cluster 38 Messier (kindly sent to me by M. M. Henry, of the Paris Observatory). It was described by Webb as " a noble cluster, arranged in an oblique cross," and Smyth says—" The very unusual shape of this cluster recalls the sagacity of Sir William Herschel's speculations upon the subject, and very much favours the idea of an attractive power lodged in the brightest part. For although the form is not globular, it is plainly to be seen that there is a tendency towards sphericity, by the swell of the dimensions as they draw near the most luminous part, denoting, as it were, a stream or tide of stars, setting towards the centre."

Sir William Herschel, speaking of a compressed cluster in Perseus, says "the large stars are arranged in lines like interwoven letters," and Webb says "it is beautifully bordered by a brighter foreshortened pentagon."

Observing with a 3-inch telescope in India, I noticed a beautiful cluster of stars, about 4° north of λ and υ Scorpii, resembling in shape a bird's foot, with remarkable streams of stars. This cluster is visible to the naked eye as a star of about the fifth magnitude.

Although these loosely-associated star clusters do not show such evidence in favour of family connection as the more closely-compacted globular clusters, still we can hardly escape from the conviction that their apparent aggregation is really due to some physical bond of union, and not merely the result of a fortuitous scattering of stars at different distances in the line of sight.

XX.

GREAT NEBULÆ.

THOSE "dim and mysterious" objects known as nebulæ present themselves under very various aspects to the inquiring eye of the astronomer. Many are small, faint, and ill-defined, even in the largest telescopes. Others are large, irregularly shaped, and comparatively bright. Some are circular or elliptical in outline; others annular, elongated, or comet-shaped. Some show a spiral structure. Some are single; others double and even triple. In the present paper we will consider the large and irregular nebulæ. Of these, the most remarkable object in the Northern Hemisphere is the great nebula in Andromeda, known to astronomers as 31 Messier, and sometimes described as "the queen of the nebulæ." On a clear moonless night it may be just detected with the naked eye as a hazy spot of light near the 4½ magnitude star *ν* Andromedæ, and even with an opera-glass it is a striking and beautiful object. It was probably known to the ancients, and it could hardly have escaped their keen eyesight in the clear Eastern skies. It was certainly seen as far back as A.D. 905. Al-Sufi, the Persian astronomer, who wrote a description of the heavens in the middle of the tenth century, speaks of it as a familiar object in his day, and the nebula is marked on a star map made in Holland about the same period. It escaped observation, however, by Tycho Brahé and Bayer. Simon Marius described it in 1612 as resembling a candle shining through a horn, and it was seen by Bulialdus in 1664, while observing the comet of that year. Halley explained it as "nothing else but the light coming from an extraordinary great space in the ether, through which a lucid medium is diffused that shines with its own proper lustre." A small adjacent nebula, a little to the north-west of it, was discovered by Le Gentil in November 1749, and a smaller and nearer one to the south by Miss Caroline Herschel in 1783. Messier, observing Le Gentil's nebula in 1764, remarked that its position and form had remained constant since its discovery, but observations in recent years have raised some suspicion of change.

In September 1847, Bond detected two dark rifts running nearly parallel to the longer axis of the great nebula. For many years the significance of these channels remained a matter of mystery, but a photograph taken by Dr. Isaac Roberts in December 1888 revealed at last their true character. They are now seen to represent the dark intervals between concentric nebulous rings into which the nebula is divided. This wonderful photograph—which will

THE GREAT NEBULA IN ANDROMEDA 31 MESSIER.

From the Original Negative taken by DR. ROBERTSON, *Dec. 29th*, 1888.

mark an epoch in astronomical research—shows us this great nebula for the first time in a clearly "intelligible form," and calls to mind the Nebular Theory of Laplace, in which the planets of the Solar System are supposed to have been evolved from rings detached from a rotating nebulous mass. In Dr. Roberts' photograph the nebula appears as a lengthened ellipse with a bright central nucleus. Its figure suggests that its real form is that of a circular mass, or rather a disc of large diameter but comparatively small thickness—like Saturn's rings—projected into an ellipse by the high inclination of its plane to the background of the heavens. The dimensions of the nebula, as shown with *certainty* on the photograph, are 1° 51′ in length and about $23\frac{1}{2}'$ in width. From these measurements I find that its apparent area is nearly three times greater than that of the full Moon. Such an extension would not, of course, be traceable in ordinary telescopes, but with a 15-inch refractor, Bond saw it still further extended. Assuming, however, the more reliable measurements indicated by the photograph, we may make an attempt to ascertain the probable size of this wonderful object. To do this with *accuracy*, it would, of course, be necessary to know the exact distance of the nebula from the Earth. But, unfortunately, such knowledge is not yet available. The nebula has not hitherto afforded any evidence of proximity to our system. The new star which suddenly blazed out near the nucleus in August 1885 was carefully measured for this purpose, but refused to reveal the secret of its distance. As the evidence of the spectroscope tended to show that the star was *in* the nebula, we may conclude that the distance is so great as to be practically immeasurable by our most refined and delicate methods of observation. Assuming, however, a minimum distance, such that light would take 160 years to traverse (corresponding to a parallax of one-fiftieth of a second of arc), we can easily calculate the dimensions of the nebula. At the great distance assumed, the apparent length shown by the photograph would indicate an actual diameter of no less than 333,000 times the Sun's distance from the Earth! Light would therefore take over five years to pass from one side to the other of this vast nebula!

It has been suggested that the Andromeda nebula may possibly represent an external universe, but the improbability of this hypothesis will appear from the consideration that even the great diameter above computed is not much greater than the distance from the Sun to the *nearest* fixed star *a* Centauri, and the limits of *our* universe are certainly vastly further from us than this. In fact, the visible universe, of which our Sun forms a member, most probably extends far beyond the distance I have assumed for the Andromeda nebula. To suit the hypothesis of an external universe, we should, therefore, be obliged to increase the distance of the nebula enormously, and this would lead us to an extravagant estimate of the real size and brightness of the new star above referred to. It seems, therefore, very improbable that this object forms an external galaxy. It is more probably a member of the vast sidereal system in which our solar system is situated; a system which, in all likelihood, includes the whole of the stars and nebulæ visible in our largest telescopes.

On the assumption that the nebula is a circular disc seen obliquely, we can also determine its position in space. Making the necessary calculations, I find that the plane of the nebula is inclined at an angle of 78° to the background of the sky, and that it probably lies at right angles, or nearly so, to the general plane of the Milky Way.

The actual constitution of this marvellous object still remains a matter of mystery. The highest powers of the largest telescopes have hitherto failed to resolve it into stars. Yet the spectroscope shows that it is probably *not* gaseous, the spectrum being continuous, like that of the great globular cluster in Hercules. The component stars may possibly be comparatively small bodies, too small to be individually visible even with our largest telescopes. Placed at the distance I have assumed for the Andromeda nebula, I find that our Sun would be reduced in brightness to a star of $9\frac{1}{2}$ magnitude. If we assume the components to have only one-hundredth of the

Sun's diameter (8660 miles), they would shine as stars of only 19½ magnitude, which no telescope yet constructed would show as individual points of light.

Of much more irregular form than the Andromeda nebula is the great nebula in the "sword" of Orion. Its cloud-like appearance might perhaps suggest a different physical constitution, and the spectroscope shows it to be a mass of glowing gas. It has been called the "Fish-mouth" nebula, from the fantastic form of its central portion. It is just visible to the unaided eye on a very clear, moonless night as a glow round the central star of the "sword," and even with an opera-glass it is a conspicuous object. It seems curious, therefore, that it should have escaped the inquiring eye of Galileo, who paid especial attention to Orion, and that its existence should have remained unknown till the year 1618, when it seems to have been first seen by Cysatus, a Swiss astronomer. A drawing of it was published by Huygens in 1659, and it has been carefully studied and mapped by several observers in recent years.

Sir John Herschel, during his visit to the Cape of Good Hope in the years 1834—1838, carefully observed and sketched the nebula, and his drawing published in the *Cape Observations* is an elaborate and valuable one. He says—"The brightest portion offers a resemblance to the head and yawning jaws of some monstrous animal, with a sort of proboscis running out from the snout." Excellent drawings

Exposure 81 minutes.

Exposure 3½ hours.

THE GREAT NEBULA IN ORION.

were also made by Bond in America, and Lassell at Malta. A comparison between the earlier drawings and those of later date has suggested the idea that great changes of form have taken place in the nebula; but probably the observed discrepancies may be simply due to different methods of delineation, rather than to changes which would, indeed, be necessarily on a gigantic scale to be perceptible at all in the comparatively short period during which the nebula has been accurately observed. Photography will, however, doubtless decide ere long whether such rapid changes are really in progress.

The nebula has been very successfully photographed by Dr. Common and Dr. Roberts, and these photographs confirm the general accuracy of the later drawings, but show a greater amount of detail.

A remarkable nebula surrounding ζ (the southern star of the belt) has also been photographed by Mr. W. H. Pickering and Dr. Max Wolf. Mr. Pickering says—"These plates show that it (the nebula in Orion) not only includes the sword handle *c*, ι and θ, but a long nebulosity extends south from ζ, others surround this star, while others, both north and south, indicate that perhaps the next increase in sensitiveness of our plates will join them all in a vast nebula many degrees in length."

Near the densest part of the nebulous glow in the "sword" of Orion lies a remarkable multiple star, known as θ Orionis, the four brighter components of which form the familiar "trapezium" of telescopists. I have seen these in the Punjab sky with a 3-inch telescope reduced in aperture to 1½ inch. Struve in 1826 detected a fifth star, and Sir John Herschel a sixth in 1830. Alvan Clark discovered a faint star within the "trapezium," and Mr. Barnard another with the great Lick telescope. Mr. Barnard has also found a faint double star just outside the trapezium, which Mr. Burnham finds a different object even with the giant telescope! Indeed, the whole region in which the nebula lies is sprinkled over with faint stars. Nearly a thousand were observed by Bond in a portion covering about 3⅓°.

Observing the nebula with his great telescope, Lord Rosse thought that the nebulous light showed symptoms of incipient resolution into stars, but this view of its constitution has been completely overthrown by the spectroscope, which shows it to consist of nothing but luminous gas. This was first demonstrated by Dr. Huggins. Referring to his earlier observations he says—"The light from the brightest parts of the nebula near the trapezium was resolved by the prisms into three bright lines, in all respects similar to those of the gaseous nebulæ. The whole of this great nebula, as far as lies within the power of my instrument, emits light which is identical in its character. The light from one part differs from the light of another in intensity alone." Further observations fully confirmed this conclusion, and showed that one of the constituents of the nebulous matter is certainly hydrogen gas, of which the complete series of spectral lines has recently been photographed by Dr. Huggins. In his first observations, Dr. Huggins was disposed to identify the brightest line—the "chief nebular line" as it is called—with a line in the spectrum of nitrogen, but recent careful measures have shown him that the nebular line does not really coincide with the nitrogen line, but is distinct from it. Professor Lockyer considers that this line coincides with the edge of a fluting in the magnesium spectrum, but Dr. Huggins and Mr. Keeler find that such is not the case. Although undoubtedly very close to the magnesium line, it is separated from it by a small but distinct interval. Spectroscopic observations tend to show, in Dr. Huggins' opinion, that "the stars of the trapezium are not merely optically connected with the nebula, but are physically bound up with it, and are very probably condensed out of the gaseous matter of the nebula"—another argument in favour of Laplace's Nebular Hypothesis, in which suns and planetary systems are supposed to have been evolved out of nebulous matter. In 1886, Dr. Copeland detected a line in the yellow portion of the spectrum, which he found to coincide with a line in the solar spectrum visible during total eclipses of the Sun. This solar line has not been identified with that of any terrestrial substance, and is supposed to indicate the presence in the Sun of some unknown substance, to which the name "helium" has been given. Dr. Copeland says—"The occurrence of this line in the spectrum of a nebula is of great interest, as affording another connecting link between gaseous nebulæ and the Sun and stars with bright line spectra, especially with that remarkable class of stars of which the first examples were detected by M.M. Wolf and Rayet in the constellation of Cygnus."[1]

Somewhat similar in its general appearance, and probably similar also in its chemical constitution, is the great nebula in the southern constellation Argo. This object, known as the "key-hole" nebula, surrounds the famous variable star η Argûs, a star which has fluctuated through all grades of brilliancy from that of Sirius to complete invisibility with the naked eye. This wonderful nebula lies in a very luminous portion of the Milky Way, and is thus described by Sir John Herschel: "It is not easy for language to convey a full impression of the beauty and sublimity of the spectacle which this nebula offers, as it enters the field of view of a telescope fixed in Right Ascension, by the diurnal motion, ushered in as it is by so glorious and innumerable a procession of stars, to which it forms a sort of climax, and in a part of the heavens otherwise full of interest."[2] Nearly in the middle of the brightest part of the nebula lies the remarkable opening known as the "key-hole," or

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[1] *Monthly Notices*, R.A.S., June 1888.

[2] *Outlines of Astronomy*, p. 653.

THE η ARGUS REGION AND NEIGHBOURING CLUSTERS IN THE SOUTHERN MILKY WAY.

From a Photograph taken by Mr. H. C. Russell, *Director of the Sydney Observatory, 23rd July, 1890.*

lemniscate. The southern portion of this curious vacuity is completely free from nebulous light, as shown in Sir John Herschel's drawing, but the northern end is partly filled in with faint nebulosity. Several other somewhat similar vacuities are also visible. Although numerous small stars are scattered over the nebula, Herschel found no tendency to resolution in the nebula itself. He says—"In no part of its extent does this nebula show any appearance of resolvability into stars, being in this respect analogous to the nebula of Orion. It has, therefore, nothing in common with the Milky Way, on the ground of which we see it projected, and may therefore be, and not improbably is, placed at an immeasurable distance behind that stratum." The evidence of the telescope has been confirmed by the spectroscope, which shows it to consist of luminous gas, like the Orion nebula. The position of some of the stars, however, with reference to the surrounding nebulous light suggests a real, and not merely an apparent, connection. The nebula with its branches covers an area of about one square degree, or about five times the area of the full moon. If placed at the distance I have assumed for the nebula in Andromeda, it must fill a vast extent of space, a space compared with which our Solar System sinks into insignificance. A comparison of drawings has suggested considerable changes in the Argo nebula both in form and brightness; but probably in the earlier delineations the fainter details were obscured by the great brilliancy of η Argûs when near its maximum. As the variable star is at present only of the seventh magnitude, the nebula is very visible to the naked eye, being, according to Mr. Abbott, brighter than the larger "Magellanic cloud." He says—"In the twilight it appears as soon as a star of the second or third magnitude, the light being white and more diffuse, very like a small white woolly cloud in a blue sky, seen in sunlight."

Much smaller than the Argo nebula, but somewhat similar in its general form, is another southern nebula known as 30 Doradûs. This wonderful object forms one of the many varied forms which, collected together, compose the larger "Magellanic cloud." It is sometimes called the "looped nebula," from the curious convolutions formed by its nebulous rays and streams. Sir John Herschel gives a beautiful drawing of it in his *Cape Observations*, and describes it as "one of the most singular and extraordinary objects which the heavens present." Near its centre is a star of the ninth magnitude, attended by several fainter stars forming a small cluster. Just south of this is a pear-shaped vacuity, similar to the "key-hole" perforation in the Argo nebula, but of proportionately larger dimensions. North of the central star there is a bright nebulous ray like the tail of a comet. Near this is a round hole, and further north three plume-like branches diverge from a common nebulous stem. The fainter portions of the nebulosity seem pierced by similar "coal sacks," features which appear to be characteristic of these large irregular nebulæ.

To satisfactorily explain the existence of these curious openings is a matter of no small difficulty. If we suppose the nebula to have a thickness comparable with its visible extent, or, in other words, that it is of a roughly spherical form, we must suppose these vacuities to represent tunnels through a gaseous mass, a not very conceivable arrangement. If, however, we consider the nebula to have but little extension in the line of sight, that is, to form a thin stratum instead of a spherical mass, a perforation through such a disc is perhaps more easily imaginable. In either case, however, it is not easy to understand how an opening through a gaseous mass can be kept open, and prevented from closing up by fluid pressure.

Many faint stars are scattered over the area occupied by 30 Doradûs, and of these Sir John Herschel gives a catalogue of 105, ranging in brightness from the ninth to the seventeenth magnitude. I am not aware whether the light of this nebula has been examined with the spectroscope, but from its general appearance it will, I think, probably prove to be gaseous.

Both the Argo nebula and 30 Doradûs are unfortunately invisible in these latitudes, but there are some other interesting objects further north. Of these may be mentioned that known as 8 Messier, which lies a little to the south-east of the fifth magnitude star 4 Sagittarii, a star close to the Ecliptic.

I found it very plain to the naked eye in the Punjab sky, and even with a telescope of only 3 inches aperture it is a glorious object. The sixth magnitude star 9 Sagittarii is involved in the nebulosity which is partly mixed up, apparently at least, with a fine cluster of stars. I have seen the cluster well with a 3-inch telescope. In the *Cape Observations* Sir John Herschel gives a drawing of this fine object, which shows several vacuities similar to those in the larger nebulæ already described. He says—"Its brighter portion may be described as consisting of three pretty distinct streaks or masses of nebula of a milky or irresolvable character, arched together at their northern extremities so as to form some resemblance to the arches of an italic letter *m* very obliquely written, and this is the aspect under which it strikes the eye on a cursory view. On closer attention these streaks are seen to be connected and run into each other below (or to the south), by branches and projections of fainter light, and to form three distinct basins, insulating oval spaces, one entirely, the other comparatively, dark." He estimated the area covered by the nebula and its branches as about one-fifth of a square degree, or about the apparent area of the full moon. Secchi found a gaseous spectrum.

About a degree north of the nebula just described lies a very curious object known as the "trifid nebula." It consists of three lobes or masses of nebulosity, separated by three dark lanes or rifts radiating from the centre near which is situated a triple star. A beautiful drawing of this nebula has been made by Trouvelot, in which he shows one of the dark rifts curving round towards the north and separating the principal portion of the nebula from another nebulous mass which contains a central star. Sir John Herschel's drawing agrees fairly well with Trouvelot's, but does not show quite so much detail. The nebula has certainly a very nebulous appearance, but the spectrum is said to be *not* gaseous! Sir John Herschel suspected a connection between the "trifid nebula" and 8 Messier. This region has been recently photographed by Mr. Barnard, of the Lick Observatory, and by Mr. Russell, at Sydney, New South Wales.

All the nebulæ described in the preceding pages lie in or close to the Milky Way—an interesting fact which seems to suggest that they form part and parcel of that wonderful zone. The nebulæ in general show little or no signs of "proper motion," that is, motion across the face of the sky, a fact which suggests a vast distance from the Earth. In the case of the Orion nebula, Mr. Keeler, of the Lick Observatory, has recently detected with the spectroscope a motion of recession in the line of sight at the rate of about 10·7 miles a second, but this is probably due, in part at least, to the Sun's known motion through space in the opposite direction.

XXI.

SPIRAL NEBULÆ.

THE Spiral Nebulæ are among the most marvellous and mysterious objects in the heavens. They were discovered by the late Earl of Rosse, with his giant 6-feet reflector, and their spiral character has been fully confirmed by Dr. Roberts' photographs. Indeed photography has recently shown some nebulæ as spirals which had not been recognized with the telescope as belonging to this interesting class.

Perhaps the most remarkable of these wonderful objects is that known as 51 Messier, which is situated in the constellation Canes Venatici, about 3° south-west of η Ursæ Majoris, the star at the end of the Great Bear's tail (or handle of "the Plough"). It may been seen in small telescopes, but these merely show two nebulæ of unequal size nearly in contact. Admiral Smyth, in his *Celestial Cycle*, describes it as "a pair of lucid white nebulæ, each with an apparent nucleus, with their nebulosities running into each other, as if under the influence of a condensing power."

Sir John Herschel saw the larger of the pair as a bright globular mass, surrounded by a nebulous ring, the ring being partially split. He thought it might possibly be an external universe, similar to our visible universe, the luminous halo corresponding to the Milky Way in our stellar system. This hypothesis was not, however, verified by large telescopes, which show the object to be really a complicated spiral. The nebula has been carefully drawn by Lord Rosse, Lassell, and Vogel, and their drawings have been substantially confirmed by photography. A photograph taken by Dr. Roberts on April 21, 1889, with an exposure of four hours, shows a bright central mass, encircled by spiral streams; one of these streams being traceable from the centre to the smaller of the two nebulæ, which looks as if it were on the eve of being thrown off from the parent mass by the force of the rotation. On the original negative, a tendency to a spiral structure is also seen in this small nebulæ. Several still smaller nebulous masses or stars are visible in the field of view, and along the course of the spiral streams. This nebula was also photographed some few years since by Dr. Common at Ealing. Dr. Huggins finds that the spectrum is continuous. It would therefore seem to be *not* gaseous, and on the Nebular Hypothesis it would evidently represent a solar system in an advanced stage of its formation.

The nebula known as 99 Messier in Virgo was also found by Lord Rosse to have a distinct spiral form

His drawing reminds one of a "Catherine wheel" in pyrotechnic displays. Key found it resolvable with an 18-inch reflecting telescope, and this observation was confirmed by D'Arrest. A photograph by M. Von Gothard shows the spiral branches very distinctly, and seems to indicate that the plane of the spiral lies nearly at right angles to the line of sight.

Another spiral nebula lies a little south of the star λ Leonis. Lord Rosse thought it resolvable into minute stars.

A photograph of the nebula known as 81 Messier in Ursa Major, taken by Dr. Roberts in March 1889, with an exposure of four hours, shows a bright central mass, with a brighter nucleus, surrounded by spiral streams. In a paper print from the original negative, kindly sent to me by Dr. Roberts, these streams are very faint, but clearly traceable. It is evident from the photograph that the plane of the spiral is inclined to the line of sight, like the orbit of a binary star. As in the case of 51 Messier, small nuclei, or stars, are traceable along the spiral branches, but there is no outstanding small nebula; and on the whole it is of a similar and more regular outline than the nebula in Canes Venatici. It may possibly be a solar system in an earlier stage of its development. The spiral character of this object was unknown to astronomers before it was photographed. Dr. Huggins finds the spectrum continuous (or *not* gaseous), but, like the great nebula in Andromeda, only faintly visible at the red end. Like the Andromeda nebula also, it is not resolvable into stars with any telescope.

Closely north of the above lies another curious object which Dr. Roberts believes to be a spiral nebula seen edgeways. It was described by Sir John Herschel as a "beautiful ray," and Lord Rosse speaks of it as "a most extraordinary object, at least 10′ in length, and crossed by several dark bends." Ingall in 1885 described it as resembling "a distaff of flax." Nuclei and dark channels are perceptible in the photograph, and its general appearance is very much like Ingall's description. Dr. Huggins finds the same spectrum as in 81 Messier, so that we may, with much probability, conclude that the two nebulæ are similar in character, and possibly differing only in their position in space.

The great nebula in Andromeda (31 Messier), "the queen of the nebulæ," as it has been aptly called, is visible to the naked eye, and was possibly known to the ancients. It is referred to by Al-Sufi, a Persian astronomer of the tenth century, as a familiar object in his day. Although the spectroscope shows that it is *not* gaseous, the largest telescopes have hitherto failed to resolve it into stars. It is of an elongated elliptical shape, and of considerable apparent size. The American astronomer, G. P. Bond, traced it to a length of 4°, and a breadth of 2½°, and observed two dark rifts running nearly parallel to the longer axis of the oval. In a beautiful photograph of this object recently taken by Dr. Roberts at Liverpool, Bond's rifts are seen to be really dark spaces between the central nucleus and surrounding rings. Here we seem to see a system in a more advanced stage of its development than appears to be the case in 51 Messier. The spiral character is nearly lost, and the spiral branches having become detached from the parent mass, have now formed rings encircling the nucleus. Dr. Roberts says "they present a general resemblance to the rings of Saturn," and that the nebula "is now for the first time seen in an intelligible form." Two adjoining nebulæ are visible on the photograph—one completely separated from the great nebula, and the other nearly so, and we are tempted to imagine with Dr. Roberts that these represent portions of the large nebula which have been detached, and are now "undergoing their transformation into planets." The truth of Laplace's Nebular Theory seems to be here clearly demonstrated.

The accompanying plates are photographs of spiral nebulæ taken by Dr. Roberts in April 1893. They have been reproduced from glass positives kindly sent to me by Dr. Roberts. In the *Monthly Notices* of the Royal Astronomical Society for December 1893, Dr. Roberts describes these photographs as follows:—

♅ I 168 *Ursæ Majoris.* "The photograph shows this to be a very interesting spiral nebula, almost perfect in outline. In the centre of the spiral is a star

H I 205 URSÆ MAJORIS $9^h\ 14^m + 31°\ 34'$.

April 12*th*, 1893. 3½ *hours exposure.*

H I 168 URSÆ MAJORIS $10^h\ 12^m + 41°\ 57'$.

of fourteenth to fifteenth magnitude, and around it are formed the convolutions, each of which is broken up into stars; four of them (omitting the bright star on the north side) are sharply defined, and the others, which are numerous, appear to be in all stages of development, between very faint star-like patches and the defined ordinary star images."

"There is still nebulosity between some of the spirals, as well as between the stars in the convolutions."

"Several photographs of spiral nebulæ have from time to time been presented to the Society, and each one of them shows the spirals to be broken up into stars, or into star-like condensations, and I think the cumulative evidence thus brought before us amounts to a demonstration of the formation of stars by the condensation of nebulosity, or by the aggregation of meteoric or other cosmic matter."

♅ I 205 *Ursæ Majoris.* "The enlarged photograph, and more clearly the negative, show the nebula to be a symmetrical ellipse, with a distinctly stellar nucleus in the midst of dense nebulosity which surrounds it. Outside this is a well-defined zone of faint nebulosity, and then a broad ring, or zone, with little if any nebulosity in it. Outside this, again, is a very dense broad ring of nebulosity, and a patch of very faint nebulosity extends beyond the ring at the *s. f.* end."

"The nebula is probably a circular or oval system seen in perspective elongated, and there are indications of condensations of matter of the ring."

"The nebula resembles, on a very small scale, the great nebula in Andromeda, and the description given by Lord Rosse agrees well with the photograph, though he could not have seen the details which are there shown."

The scale of the photographs is 1 millimetre to 24″ of arc.

XXII.

PLANETARY NEBULÆ.

PLANETARY nebulæ are among the most remarkable and interesting objects in the heavens. They were so named by Sir W. Herschel from their resemblance to planetary discs. This supposed similitude applies only to their general uniformity of brightness, and to the absence of any definite nucleus or brighter portion, at least when viewed with telescopes of no great power. In intrinsic brilliancy they are of course vastly inferior to the planets, being usually very faint objects, and only to be well seen with powerful telescopes. About three-fourths of the known planetary nebulæ are situated in the Southern Hemisphere; but there are some interesting examples north of the Equator.

One of the most remarkable of these wonderful objects is that known as 97 Messier. It was discovered by Méchain in 1781, and lies about 2° (four diameters of the Moon) to the south-east of the star β Ursæ Majoris—the southern of the two "pointers." It has an apparent diameter so large, that if we consider it placed at the distance of the nearest fixed star, it would fill a sphere the diameter of which would be about three and a half times that of the orbit of Neptune. In Sir W. Herschel's telescope its light appeared nearly uniform; but Lord Rosse's great reflector has disclosed the existence of two openings with apparently a stellar point in each vacuity. From this peculiarity it has been termed the "Owl nebula." One of the stars seems to have disappeared since the year 1850, a fact which adds to its interest and mystery. Dr. Huggins finds the spectrum gaseous.

Close to the pole of the ecliptic (between δ and ζ Draconis) is a remarkable planetary nebula, known to astronomers as Herschel iv. 37. Smyth describes it as "a remarkably bright and pale blue object." Webb saw it as "a very luminous disc, much like a considerable star out of focus." Sir W. Herschel saw a very small nucleus which Bird estimated as equal to a tenth magnitude star in 1863, and D'Arrest to one of the eleventh. Examined with the great Lick telescope, Professor Holden found it "apparently composed of rings overlying each other," which he thinks are probably "arranged in space in the form of a true helix."

The diameter of the nebula is about 20″. Brunnow found a parallax of 0·047″. This would make its actual diameter about 425 times the Sun's distance from the Earth, or about 39,478,000,000 miles! Bredechin, however, finds a parallax of only 0·009″, which would indicate a diameter of 2222 times the Sun's distance, or 1111 the diameter of the Earth's orbit! Such are the stupendous objects which astronomy reveals to our wondering gaze.

A little to the south-west of the fifth magnitude star 51 Herculis (between β and δ) is a small planetary nebula, discovered by Struve. D'Arrest estimated its light as equal to that of a star of the eighth magnitude. There are several stars in the field with which the light of the pale blue nebula can be conveniently compared. Webb found it very bright, but not sharply defined, and—as Herschel described it—exactly like a star out of focus. In Lord Rosse's telescope it appeared of an intense blue. Secchi thought he could resolve it into minute stars with a magnifying power of 1500; but in this he was evidently mistaken, for the spectroscope has decided that its nature is gaseous.

Another interesting object of this class is found closely preceding the fifth magnitude star ν Aquarii. It was discovered by Sir W. Herschel in 1782, and forms one of nine rare celestial objects given by Struve, who saw it of a well-marked elliptical form. Admiral Smyth described it in 1836 as "bright to the very disc, and but for its pale blue tint, would be a very miniature of Venus." Within the larger nebulosity Lassell could detect a brighter elliptic ring.

Secchi suspected it to be a mass of small stars; but Dr. Huggins' spectroscope shows it to be nothing but luminous gas. It has an apparent diameter of about 20″ of arc, and if placed at only the distance of α Centauri it would more than fill the orbit of Saturn. Examined with the great telescope of the Lick Observatory, Professor Holden found it a wonderful object of a pale blue colour, with a central ring, which he compares to a "footprint left in the wet sand on a sea-beach."

About 4½° following γ Eridani lies another remarkable planetary nebula. Smyth describes it as "a splendid though not very conspicuous object of a greyish-white colour. It is somewhat like a large star out of focus with a planetary aspect." Sir W. Herschel found it somewhat elliptical and not well defined, and thought it might possibly be a very compressed cluster of stars at an immense distance from the Earth. Observing it at the Cape of Good Hope, Sir J. Herschel concluded that it is "a very distant and highly-compressed cluster." These views have been confirmed with the spectroscope by Dr. Huggins, who found that the spectrum, although deficient at the red end, like the great nebula in Andromeda, is *not* gaseous. Lassell describes it as the most wonderful object of the kind he had ever seen—an apparently stellar point in the centre of a circular opening which is again surrounded by a fainter nebulosity. D'Arrest thought the edges resolvable, and Lord Rosse considered the nucleus to be granular in his great reflector.

About 2° south of the star μ Hydræ is a planetary nebula which Smyth describes as resembling Jupiter in "size, equable light, and colour." He thought that, "whatever be its nature," it "must be of awfully enormous magnitude." Webb found it of "a steady pale blue light," and Sir J. Herschel at the Cape found its colour "a decided blue"—a feature which seems very characteristic of these extraordinary objects. Sir W. Herschel failed to resolve it into stars; Secchi found it broken up into apparently stellar points and a sparkling ring; but Dr. Huggins finds the spectrum gaseous, so that Secchi's points can scarcely be stellar.

Many examples of this interesting class of nebulæ were observed by Sir John Herschel during his residence at the Cape of Good Hope. His descriptions of some of these are given in my *Scenery of the Heavens.*[1]

The gaseous character of most of these planetary nebulæ led Professor Pickering to the conclusion that possibly an examination with the spectroscope might lead to the discovery of objects of this class, which—owing to their small apparent diameters—might escape detection with the telescope, and merely appear like small stars, even when examined with telescopes of considerable power. The light of an ordinary star is seen spread out by the prism into a

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[1] pp. 210—212.

coloured band of light; but the light of a gaseous nebula, being chiefly of one colour, forms merely a small point or disc of light. Following this plan, a systematic search for such objects has been instituted at the Harvard Observatory (U.S.A.), a direct-vision prism being placed for the purpose between the eye-piece and the object-glass of the 15-inch refractor of that Observatory. A large number of stars have been carefully examined in this way, and the search has disclosed the existence of some small planetary nebulæ hitherto unsuspected. In the first sweep, made on July 13, 1880, an object entered the field of view of the observing telescope, having a spectrum consisting of a bright point of light, quite unlike that of the ordinary stellar spectrum. This proved to be a small planetary nebula. It lies in the Milky Way near the star λ Sagittarii, and measures of its light showed that it was about the eleventh magnitude. Its disc is so small that probably its nebulous nature would never have been detected with the telescope. On the following evening a similar object was found in the same vicinity. It was somewhat fainter than the first, but with rather a larger disc. This region of the heavens was selected for observation because it contains four out of the 50 planetary nebulæ previously known to astronomers.

On August 28 an object was met with, having a remarkable spectrum with "two bright bands near the ends of a faint continuous spectrum."

It was soon identified with the star Oeltzen Argelander, No. 17,681, which lies near μ Sagittarii. It was observed once by Argelander, and twice at Washington, and on each occasion was recorded as an ordinary fixed star. These observations show that it existed in its present position and brightness over thirty years previously. An examination of the remarkable spectrum shown by this object, indicates that the brighter parts are bands and not lines. One of these bands lies near the sodium line D of the solar spectrum, and another in the blue between F and G. Professor Pickering says the spectrum of this object "is unlike that of any other source of light as far as is yet known." "On the other hand," he says, "it resembles a star in other respects, showing no disc, and having a much greater intrinsic brightness than other nebulæ."

Another new object, similar to the preceding, was detected on September 2, 1880, and in the same region of the heavens. It resembles a star of the thirteenth magnitude, and is probably the faintest planetary nebula hitherto discovered.

XXIII.

CELESTIAL PHOTOGRAPHY.

THE first idea of photographing the heavenly bodies may be dated back to the great discovery made by Daguerre and Niepce, and communicated by Arago to the French Academy on August 19, 1839. Daguerre attempted to photograph the Moon in 1840, but apparently without much success, and to Professor J. Draper seems due the credit of obtaining, in the same year, the first lunar photograph. He was also the first to photograph the solar spectrum. This was accomplished in 1843. The earlier photographs were called daguerreotypes, after the inventor, and a series of plates of an eclipse of the Sun, now almost obliterated by time, are preserved in the museum of the Paris Observatory. These plates have no date, but are probably photographs of the total eclipse of July 8, 1842—an eclipse which was also photographed by Majochhi at Milan.

In April 1845, Messrs. Fizeau and Foucault obtained a good photograph of the Sun with an exposure of one-sixtieth of a second, which showed some sun-spots, and also gave some indications of the fact, now well known, that the centre of the solar disc is brighter than the portions near the limb.

The solar eclipse of July 28, 1851, was photographed by Berkowski at Koenigsberg, and upon this plate are seen for the first time traces of the solar corona and red flames.

In 1853 and 1854 Mr. Hartnup, at Liverpool, and others, obtained good photographs of the Moon, and the solar eclipse of May 26, 1854, was photographed by Professor Bartlett at West Point (U.S.A.).

In 1856 the late Mr. Warren de la Rue established an observatory at Cranford, having a reflecting telescope made by himself of 13 inches aperture and 10 feet focal length. In the following year he obtained with this instrument good photographs of the Moon, Jupiter, and Saturn. It may be mentioned here that by photographing the Moon at suitable intervals, and taking advantage of the small changes caused by libration, it is possible to obtain pictures which, when viewed in a stereoscope, give the appearance presented by a spherical body.

In 1859 Mr. de la Rue constructed a large photoheliograph at Kew, and with this instrument over 2000 photographs of the Sun's surface were obtained in the years 1862 to 1872. In the years 1850 to 1871 six eclipses of the Sun were photographed with varying success, but most of them showed details of the corona and protuberances. Photography was also applied to the observation of the transits of Venus in 1874 and 1882, but the results obtained in this way were of doubtful value.

The first attempt to photograph the stars seems to have been made in 1850 by W. C. Bond and Whipple, with the equatorial telescope of the Harvard Observatory (U.S.A.). They succeeded in obtaining images of the bright star Vega and the double star Castor, but the daguerreotype plates used were not sufficiently sensitive for such delicate work. A very long exposure was necessary for even a bright star, and the impossibility of obtaining impressions of the fainter stars led them to abandon their efforts. On the introduction of the collodion process, however, in 1857, Bond again attempted to photograph the brighter stars, and succeeded in obtaining images of stars of the first and second magnitude with an exposure of only two seconds. He also photographed the double star Mizar (ζ Ursæ Majoris), and from measures of the photographed images he obtained a very accurate result of the position, angle, and distance between the components of this well-known pair, a result which agreed closely with Struve's measures made directly with the micrometer.

In the year 1864 Dr. Rutherford, of New York, constructed an object glass of 11 inches aperture for the photography of the stars, which gave better results than a mirror of over 23 inches in diameter.

With this instrument he obtained good photographs of the Præsepe and the Pleiades, which showed stars down to the ninth magnitude. Following Rutherford's methods, Dr. Gould, in the years 1870 to 1882, photographed the principal star clusters in the Southern Hemisphere at the Cordoba Observatory in the Argentine Republic, and obtained plates showing stars to the tenth and eleventh magnitudes, some of them containing 500 stars to the square degree.

We now arrive at an epoch when the photography of celestial bodies was much facilitated by the introduction of the dry plate process. The old wet plate process with collodion required enormously long exposures, and was difficult to manipulate. The discovery of the gelatino-bromide of silver process, however, allowed much more sensitive plates to be used, thus reducing the time of exposure necessary for faint stars, and permitting more work to be done in a given time. The advantage of a short exposure in a climate like that of England is obvious, for with a long exposure the sky may cloud over before the photograph is finished. The introduction of the dry plate process gave a fresh impetus to celestial photography. In the year 1881 Professor Draper obtained a good photograph of the great nebula in Orion with an exposure of one hour, and a still better photograph of this wonderful object was obtained by Dr. Common in January 1883.

About this time Professor Pickering, at the Harvard Observatory, commenced to take a series of plates showing all stars to the naked eye, and this work is now far advanced towards completion.

The idea of forming a complete chart of the whole sky by means of photography seems to have been originally suggested by Mr. de la Rue about the year 1857, but the possibility of carrying out the idea does not seem to have been recognized until Dr. Gill, in 1882, obtained a photograph of the comet of that year with an exposure of 1 hour 50 minutes. On this photograph numerous faint stars are sharply shown, and Dr. Gill's success proved that a photographic chart of the sky was now possible. The same suggestion seems to have been also made by Dr. Common in the same year.

In the year 1884, Messrs. Paul and Prosper Henry, of the Paris Observatory, while attempting to complete by eye observations at the telescope the ecliptic charts left unfinished by Chacornac at his death in 1873, came across regions of the Milky Way so rich in the fainter stars, which it was necessary to show on these charts, that they found it impossible to record them in their correct places. The idea then occurred to them that the work might be successfully accomplished by the aid of photography. To carry out this plan they constructed a special photographic equatorial telescope with an object glass of 13 inches aperture, and with lenses corrected for photographic work. To this instrument is attached a second telescope of about 9½ inches aperture, which serves as a finder in following the stars to be photographed, and corrects any error in the rate of the clock which drives the whole apparatus. Complete success crowned the efforts of these admirable astronomers, and the excellence of the stellar photographs obtained can only be appreciated by those who have seen the originals. The present writer has in his possession a number of paper prints from the original negatives, very kindly sent to him by the brothers Henry. On these the stars are shown as perfectly round white discs on a black background, and their extreme beauty can hardly be adequately described.

The duration of exposure necessary for obtaining images of stars of different magnitudes varies, of course, with the brightness. At the Paris Observatory it has been found that, with the extra sensitive plates now used for the purpose, stars of the first magnitude can be photographed with an exposure of $\frac{1}{200}$th of a second, and stars of the second magnitude in about $\frac{1}{100}$th of a second. Stars of the sixth magnitude—about the faintest visible to ordinary eyesight without optical aid—take about half a second; those of the ninth magnitude about eight seconds; those of the twelfth about two minutes; and for stars of the sixteenth magnitude—about the faintest visible in the largest telescopes—an exposure of 1 hour 20 minutes is required. The long exposures necessary to obtain images of the fainter stars cause those of the brighter stars to be much "over exposed," and these latter appear on the photographs as discs of considerable size. There is, however, a relation between the size of the disc and the brightness of the star, and estimations of relative brightness can be obtained by measuring the diameter of the discs with an instrument which has been invented for the purpose. Stars of a red colour are, of course, more difficult to photograph, and the images of these ruddy stars come out with much smaller dics than those of white stars of equal brilliancy to the eye.

The superiority of the photographic method of stellar mapping over eye observations will be understood from the fact that a chart of the Pleiades constructed by M. Wolf with a large telescope shows 671 stars in this well-known cluster, while on a photograph taken at the Paris Observatory with an exposure of three hours, over 2000 stars can be counted! Indeed faint stars are visible on these stellar photographs which cannot be seen by the eye in the telescope with which the photographs were taken. In fact, the success attained at the Paris Observatory in stellar photography is such that the late superintendent, Admiral Mouchez, remarked that "at first sight a doubt might be entertained as to the accuracy of the results."

Good photographs have also been obtained by Dr. Roberts, using a reflecting telescope of 20 inches aperture. On a plate of a portion of the Milky Way in Cygnus, taken in August 1837, with an exposure of an hour, no less than 16,000 stars can be counted on a space of about four square degrees.

Photographs of double stars have also been taken at the Paris Observatory, and from these accurate measures of position can be obtained which will be of great value in the calculations of the orbits of these interesting systems.

To avoid the danger of accidental specks on the plates being mistaken for stars, the plan has been tried at the Paris Observatory of giving *three* exposures on *each* plate, the three images forming a small equilateral triangle, which can only be seen with the aid of a microscope. Another advantage of this method is that the time of exposure for each image may be shortened, the triple image producing a combination which is more easily seen than a single image. Should one of the minor planets between Mars and Jupiter happen to be present in the region photographed, it could at once be detected by the distorted shape of the small triangle; and it is believed that even a planet beyond Neptune might be detected in this way. If a trans-Neptunian planet exists it will probably be discovered by photography. Several of the minor planets have already been discovered by this method.

For the fainter stars, however, an exposure of one hour is necessary for *each* image, and the continuous exposure of three hours required for the triple image is a great strain on the observer's eye and patience, and forms a serious objection to the general adoption of this plan. By the use of more sensitive plates and larger telescopes, the time of exposure will probably be considerably reduced in the future. When examined with a microscope, however, the appearance of the stellar images is so peculiar that accidental spots can be easily distinguished. With a high power the images look like globular clusters of stars as seen in a telescope, and they have been described as resembling "a heap of shingle." For this reason a *single* exposure will probably be adopted in constructing a chart of the heavens.

In the year 1887 an International Conference of astronomers was held at Paris, for the purpose of arranging the details of a photographic chart of the whole heavens on a uniform plan. The Conference was composed of fifty-six astronomers, representing sixteen different nations. It was resolved that refracting telescopes of about 13 inches aperture should be used in the work. A series of plates will first be taken showing stars to the eleventh magnitude. From these a catalogue will be formed, which will serve as a foundation and reference for all similar work in the future. This catalogue will, it is supposed, include about one and a half million of stars. A second set of plates will also be obtained showing stars to the fourteenth magnitude inclusive, and these will probably contain about 20,000,000 stars.

Another Congress was held in Paris in September 1889, when further details were considered and arranged.

The work will be divided among a number of observatories in different parts of the world, and already some progress has been made in the construction of the necessary telescopes and the carrying out of the plan, which, it is hoped, will be brought to a successful conclusion before many years have elapsed.

Some remarkable results have already been obtained by photography. The satellites of Mars and Neptune and Saturn's rings have been photographed. Photographs of the great Orion nebula by Drs. Common and Roberts show a great extension of this wonderful object. The great nebula in Andromeda, the spiral nebulæ, and others, have been successfully photographed by Dr. Roberts. In the Andromeda nebula, we see that the whole mass is breaking up into rings of nebulous matter, and the photograph suggests unmistakably the probable formation of a solar system on the lines of Laplace's Nebular Hypothesis.

Photography has also been successfully employed in the determination of stellar distances and in the study of stellar spectra. A catalogue of the spectra of over 10,000 stars, and entitled *The Draper Catalogue*, has recently issued from the Harvard Observatory. It has been formed in honour of the late

Dr. Henry Draper, and forms a fitting monument to the memory of that distinguished astronomer. An examination of the photographed spectra has revealed the existence of some very close binary stars revolving in unusually short periods—double stars of which the components are so close that the largest telescopes in existence have failed to show them as anything but single stars.

Photographs of the Milky Way have also been successfully taken by means of a portrait lens strapped to a telescope driven by clockwork. The pictures obtained are very beautiful, and give promise of still better results in the future. The study of these and the stellar charts, when completed, will probably add considerably to our knowledge of the construction of the sidereal universe.

The preceding short sketch of the rise and progress of celestial photography will show that we may look forward in the future to a great increase of astronomical knowledge by its aid. Assisted by even larger telescopes and more sensitive plates than we now possess, the heavens will be studied in a way undreamt of by our ancestors, and, in the words of a well-known astronomer, "the records that future astronomers will use will not be the written impressions of dead men's views, but veritable images of the different objects of the heavens recorded by themselves as they existed."

XXIV.

ASTRONOMY WITHOUT A TELESCOPE.

SOME years since Sir Edmund Beckett (now Baron Grimthorpe) published a book entitled *Astronomy without Mathematics.* Many may think that these two sciences could not be separated; but it is quite true that much may be learned about the heavenly bodies without any deep knowledge of mathematical science. Another work has recently been published by an American writer—Mr. Garrett P. Serviss—with the title *Astronomy with an Opera-glass,* in which he shows how much may be seen with such modest "means" as an opera-glass of little over one inch and a half in diameter. With such an instrument, or one slightly larger, really good work may be done in the observations of the brighter variable stars, and it may be even used for the discovery of new objects of this class, which are not much below the range of naked-eye vision.

In the following pages I propose to go a step further than Mr. Serviss has done, and to point out the knowledge of astronomy which may be acquired without an instrument of *any* kind, the observer being aided only by the naked or "unarmed" eye, or, as one of my American correspondents phrases it, the "undraped optic"! I hope to show that something, at least, may be learned in this way of what Mr. Serviss terms "the celestial city, whose temples are suns, and whose streets are the pathways of light."

It must be remembered that astronomy was studied ages before the invention of the telescope, and that the ancient astronomers gained, without any optical assistance, a considerable amount of knowledge respecting the heavenly bodies.

Let us first consider the stars visible to the naked eye. The number of these down to the sixth magnitude—about the faintest that average eyesight can see—is, for both hemispheres, about 6000. The number, therefore, visible at *one* time from any given place is about 3000. Possibly double this number might be seen by those gifted with exceptionally keen eyesight; but even this is a comparatively small number, scattered as it is over so large an area. Those who do not possess the power of effective enumeration estimate the number visible to the naked eye as considerably greater than is really the case. This is partly due to the irregular distribution of the lucid stars over the celestial vault, and partly to the effect which the aspect of the starry sky produces on the imagination; the fact of the stars increasing in number as they diminish in brightness inducing us to suspect the presence of points of light which we do not actually see. An attempt to count those visible with *certainty* in any selected portion of the sky will, however, convince any intelligent person that the number, far from being large, is really very small, and that the idea, which some entertain, of a countless multitude, is merely an optical illusion, and a popular fallacy which has no foundation in fact. Of course the number visible in telescopes is very considerable. Perhaps with the largest telescopes 100,000,000 could be seen; but even this large number is very far from being "countless." The present population of the earth is about 1,400,000,000, or about 14 times the number of the *visible* stars!

The first thing to be done in studying the heavens with the naked eye is to learn the positions and names of the brighter stars; and from these the fainter ones may easily be identified by means of a star atlas. Those who study the stars in this way have probably a more intimate knowledge of the starry heavens than professional astronomers, who generally find the stars—at least the fainter ones—by referring to a catalogue of stars, and then setting their telescope to the place indicated by the figures given in the catalogue. Although the famous astronomer Sir William Herschel possessed several large telescopes, he also studied the stars with the naked eye, and it is related of this great observer that he could without hesitation identify any star he could see in this way, by its name, letter, or number! Such an exhaustive knowledge of the heavens is of course very rare; but an acquaintance with all the brighter stars can easily be acquired by any person of ordinary intelligence.

The "Plough," or Great Bear, is familiar to most people. This remarkable group of seven stars will be found very useful in identifying some of the brighter stars. The two stars furthest from the "tail" are called the "pointers," as they point nearly to the Pole Star, or star to which the axis of the earth nearly points. I say "nearly," for the Pole Star is not *exactly* at the pole, but distant from it about three diameters of the Moon. The northern of these stars is known to astronomers by the Greek letter Alpha, and the southern as Beta. The others, following the order of the figure, are known by the letters Gamma, Delta (the faintest of the seven), Epsilon, Zeta, and Eta. Now, if the curve formed by the three stars in the tail, Epsilon, Zeta, and Eta, is continued on, it will pass near a very bright star. This is Arcturus (Alpha of the constellation Boötes), one of the brightest stars visible in Europe. Again, if we draw an imaginary line from Gamma to Beta, and produce it, it will pass near another bright star. This is Capella (Alpha of Auriga, "the Charioteer" referred to by Tennyson).

Again, if we draw a line from Delta to Beta, and produce it, it will pass near the tolerably bright stars, Castor and Pollux (Alpha and Beta of the constellation Gemini, or the Twins), the northern of the two being Castor. Another line from Delta to Gamma produced will pass near a bright star called Regulus (Alpha of Leo, the Lion). Another line from Beta to Eta will pass near a group called Corona Borealis, or the Northern Crown.

On the opposite side of the Pole Star from the Plough, a group of five conspicuous stars will be found, forming a figure shaped somewhat like a W. This is Cassiopeia's Chair. Commencing with the most westerly of the five, these stars are known as Beta, Alpha, Gamma, Delta, and Eta. Like the stars of the Plough, those of Cassiopeia's Chair may be used to find other stars. For instance, a line drawn from Beta to Alpha passes close to a star known as Gamma in Andromeda ; and the same line produced in the opposite direction will pass a little north of the bright star Vega (Alpha Lyræ), one of the brightest stars in the northern heavens. A line from Gamma to Alpha produced will pass through the well-known "Square of Pegasus."

To the east of Vega lies Cygnus, or the Swan, a well-known northern constellation. It may be recognized by the long cross formed by its principal stars, Alpha, Beta, Gamma, Delta, and Epsilon ; Alpha, or Deneb, being the most northern and brightest, and Beta the most southern and faintest of the five.

To the south-east of Cassiopeia's Chair lies the constellation Perseus, distinguished by its well-known festoon or curve of stars. South of this lies the constellation Taurus, or the Bull, which contains the well-known groups or clusters, the Pleiades and the Hyades. The Pleiades form perhaps the most remarkable group of stars in the heavens, and are easily found, when above the horizon, in the winter months in England. To ordinary eyesight the cluster consists of six stars. Some persons gifted with exceptionally keen eyesight have, however, seen eleven or twelve. A map of the Pleiades made in the sixteenth century shows eleven stars very correctly. This was drawn, of course, from observations made with a measuring instrument, but without the aid of a telescope. The observer (I think it was Möstlin, Kepler's tutor) must have possessed wonderfully sharp eyesight. The Hyades form a V-shaped figure, and contain the bright reddish star Aldebaran.

South of Taurus and Gemini will be found the splendid constellation of Orion, perhaps the most brilliant group of stars visible in either hemisphere. A remarkable quadrilateral figure is formed by its four stars, Betelgeuse (Alpha) and Gamma on the north, and Rigel (Beta) and Kappa on the south. Of these Betelgeuse and Rigel are bright stars of the first magnitude. Betelgeuse is distinctly reddish, and also slightly variable in its light. Rigel is a beautiful white star. In the middle of the quadrilateral are three stars of the second magnitude, nearly in a straight line, known as Delta, Epsilon, and Zeta, Delta being the northern of the three. These form

Orion's "belt." South of these are three fainter stars, also in a straight line, forming the "sword" of Orion. Surrounding the central star of the "sword" is "the great nebula in Orion," one of the finest objects in the heavens. It is barely visible to the naked eye, but may be seen with a good opera-glass.

To the south-east of Orion will be found Sirius, the brightest star in the heavens. It is the chief star of the constellation Canis Major, or the Great Dog, and has been well termed "the monarch of the skies," from its great brilliancy.

The bright star Regulus, referred to above, is situated in a remarkable group of stars shaped like a sickle, and known as "the Sickle in Leo." Regulus lies at the extremity of the handle. Leo is well placed for observation in April and May.

With the help of the bright stars mentioned, and the aid of a star atlas, the other constellations may be easily identified.

The famous group called the Southern Cross is not visible in England, but forms a conspicuous object in the southern heavens. It has formed a subject of interest since the earliest ages of antiquity. Its component stars are, however, not so brilliant as some suppose, the two brightest being between the first and second magnitude, the next of the second, and one between the third and fourth magnitudes. Near the Southern Cross are two bright stars known as Alpha and Beta of the Centaur.

Among the stars are many objects known as "double stars." These consist of two stars very close together, but which appear to the naked eye only as single stars. Some are triple, and even quadruple. Of these double stars there are now about 10,000 known to astronomers, but they are only visible with a telescope. Some, indeed, are so close that the highest powers of the very largest telescopes are necessary to see them as anything but single stars. Of the naked-eye stars there are, however, some apparently so close that they present very much the appearance of real double stars as seen in a telescope. These, although not recognized by astronomers as double stars, have been termed "naked-eye doubles." Houzeau found that the brighter the stars are, the easier it is to separate them; and that for small stars, about 15′ of arc, or half the Moon's apparent diameter, is about the limit below which the naked eye cannot see a faint star double.

Of the "naked-eye doubles," perhaps the most remarkable is Mizar, the middle star in the "tail" of the Great Bear. Close to it is a small star, sometimes called "Jack on the Middle Horse." It was known to the ancient astronomers as Alcor, or "the test," as it was *then* considered a test of excellent eyesight. Whether it has really brightened seems doubtful, but at present it is perhaps visible to *ordinary* eyesight. Some, however fail to see it, while to others with keener vision it seems as plain as the proverbial "pike-staff." The star Alpha Capricorni consists of two stars which, although closer than Mizar and Alcor, are more equal in brightness, and may be easily seen with the naked eye on a clear night. Nu Sagittarii may also be seen double in this way. Theta Tauri, in the Hyades, is another object which some eyes can see distinctly double ; also Kappa Tauri, a little north of the Hyades ; Omicron Cygni, a little to the west of Alpha Cygni (Deneb), is another example. On a very fine night two stars may be seen in Iota Orionis, the most southern star in the "sword." Near Gamma Leonis, one of the brightest stars in the "sickle," is a star of the sixth magnitude, which some can see without optical aid.

The most severe test in the Northern Hemisphere is, however, Epsilon Lyræ, the northern of two small stars which form a little triangle with the brilliant Vega. This, to some eyes, appears double. The famous German astronomer Bessel is said to have so seen it at thirteen years of age. To most people, however, it will perhaps appear only elongated. This is a very remarkable star, as each of the components is seen to be a close double when examined with a good telescope, and between the pairs are several fainter stars.

Among those interesting objects, the variable stars, are several which may be well observed without optical assistance. Of these may be mentioned

Algol, of which all the fluctuations of light may be easily observed with the naked eye; Mira Ceti, which may be well observed when at its brightest; Lambda Tauri, a variable star of the Algol type; Betelgeuse (Alpha Orionis), which is slightly variable; Zeta Geminorum, a fourth magnitude star, which varies about three-quarters of a magnitude in a period of about ten days; R. Hydræ, which is visible to the naked eye at maximum; Beta Lyræ, period about thirteen days; Eta Aquilæ, period about seven days; and Delta Cephei, which varies about one magnitude in a period of a little over five days. Of all these stars useful observations may be made without optical assistance of any sort.

Observations, and even discoveries, of new or "temporary" stars may also be made with the naked eye. This occurred in the case of the "temporary" stars of 1572, 1604, 1670, 1866, and 1876, but of course these were bright objects at the time of their discovery. Hind's "new star" of 1848 in Ophiuchus was, however, only of the fifth magnitude when it appeared, and it might have escaped detection with the naked eye. A star of this magnitude might, however, be easily detected by an observer who is familiar with the principal stars of a constellation.[1]

The Milky Way may perhaps be better seen with

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[1] A new star was discovered near Chi Aurigæ in January 1892. It was discovered with a hand telescope by Dr. T. A. Anderson of Edinburgh. When at its brightest it was visible to the naked eye.

the naked eye than with any instrument, although an opera-glass brings out well, in some places, its more delicate details. A mere passing glance might lead a casual observer to suppose that the Galaxy stretched as a band of nearly uniform brightness across the heavens. But good eyesight, careful attention, and a clear sky will soon disclose numerous details previously unsuspected; streams and rays of different brightness, intersected by rifts of darkness, and interspersed with spots and channels of comparatively starless spaces. An excellent drawing of the Milky Way—the result of five years' observations with the naked eye alone—has recently been completed by Dr. Otto Boeddicker, at Lord Rosse's observatory in Ireland. This beautiful picture is exquisitely drawn, and shows a wonderful amount of detail. A writer in the *Saturday Review* of November 30, 1889, says, "His maps are in many respects a completely new disclosure. Features barely suspected before, come out in them as evident and persistent; every previous representation appears, by comparison, *structureless*." This shows what can be done with the naked eye in the study of this wonderful zone.

Among the Nebulæ and clusters there are not many objects visible to the naked eye. A hazy appearance about the middle star in Orion's "sword" indicates the presence of the "great Nebula," one of the finest objects in the heavens. The "great Nebula in Andromeda," aptly termed "the Queen of the

Nebulæ," is distinctly visible to the naked eye on a very clear night. It lies near the four and a half magnitude star, Nu Andromedæ (a few degrees north of Beta Andromedæ), and may be well seen in the early evening hours in the month of January, when it is high in the sky. It somewhat resembles a small comet. This Nebula was known long before the invention of the telescope, and it was described by one of the earlier astronomers as resembling "a candle shining through horn," a not inapt description.

Of star clusters visible without optical aid may be mentioned the double cluster Chi Persei, which appears to the eye as a luminous spot in the Milky Way; the cluster known as 35 Messeir, a little north of Eta Geminorum, just visible to the naked eye on a very clear night; and there are others in the Southern Hemisphere, notably the globular cluster known as Omega in the Centaur, which shines as a hazy star of the fourth magnitude. Among the clusters may perhaps be included the Præsepe, or the "Bee-hive," in Cancer, which has a nebulous appearance to the naked eye.

Coming now to the Solar system, the Sun and Moon, of course, first attract attention. Cases of sun-spots visible to the naked eye are recorded, but of course spots of such enormous size are of rare occurrence.[1] Of lunar detail, but little can be seen

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[1] A remarkable spot of this kind was visible in February 1892, and another in February 1894.

without a telescope of some sort, but the larger markings are sufficiently distinct to good eyesight to convince the observer that they do not alter perceptibly, thus showing clearly that the Moon always turns the same side to the Earth.

Of the planets, nothing of their appearance in the telescope can, of course, be seen with the naked eye, but it is easy to identify the brighter planets. Mercury, owing to its proximity to the Sun, is rarely visible in this country, but, when favourably situated, it may sometimes be detected near the Sun shortly after sunset, or a little before sunrise. Notwithstanding the difficulty of seeing it, it was well known to the ancients, an observation of the planet dating back to 264 B.C. It is easier, however, to see in more southern latitudes, and I have frequently observed it as bright as a star of the first magnitude in the clear air of the Punjab sky. I have also seen it on several occasions in Ireland, and the Rev. S. J. Johnson, F.R.A.S., tells me he has seen it with the naked eye no less than 100 times in the south of England. The brilliant planet Venus can hardly be mistaken when seen in the morning or evening sky. When at its brightest it considerably exceeds Jupiter and Mars, and far surpasses Sirius, the brightest star in the heavens.

If a very bright planet is seen rising at sunset, it cannot be Venus, which is never seen beyond a limited distance from the sun. The observer may, therefore, conclude with certainty that the planet is either Jupiter or Mars. The latter, which occasionally rivals Jupiter in brilliancy, may be easily distinguished from the "giant planet" by its distinctly reddish colour. Saturn shines with a yellowish light, and is never so bright as Mars or Jupiter when at their brightest. The planet Uranus is just visible to the naked eye, and may be found without optical assistance, when its position is accurately known. At present (1894) it lies near the star Alpha Libræ.

Some observers think that they can see the crescent of Venus with the naked eye when the planet is in that phase, but this seems very doubtful. Cases have been recorded of one or two of the satellites of Jupiter having been seen with the unaided eyesight, but few are gifted with such keen vision.

Occultations of bright stars may be well seen with the naked eye, especially when they pass behind the moon's *dark* limb, and as the disappearance of a star is practically instantaneous, really valuable observations may be made without a telescope, by merely noting the exact time at which the star vanishes.

Most of the comets discovered by astronomers are small and faint, and only visible in good telescopes. At intervals, however, a brilliant visitor appears on the scene, and its path among the stars may be watched from night to night with the naked eye. Before the invention of the telescope, bright comets were watched in this way, and their course recorded so carefully, that it has been found possible to calculate their orbits with some approach to accuracy. In these days of large telescopes and instruments of almost mathematical precision, such a method of observation is of course superseded ; but we may still watch the movements of a bright comet with interest, and note its apparent path across the sky with pleasure and profit.

Shooting-stars and fireballs may be best observed with the naked eye, and the excellent work done in this way by Mr. W. F. Denning, F.R.A.S., should encourage others to take up this interesting branch of astronomy.

Another object which may be well seen with the naked eye—indeed it may be best observed in this way—is the Zodiacal Light. This is a lenticular or cone-shaped beam of light, which makes its appearance at certain times of the year, above the Eastern horizon before the dawn, and above the Western horizon after sunset, when the sky is clear and the moon absent. In the tropics it is much more easily seen, the twilight being shorter, and I have often observed it in India shining with great brilliancy. But even in this country useful observations may be made of its position among the stars, its brilliancy relative to the Milky Way, and other details. I have often observed it in the west of Ireland, and have sometimes seen it exceeding in brightness the Galaxy between Cygnus and Cassiopeia.

From the above sketch my readers will see how much may be learned of astronomy without optical assistance of any kind, and I hope that those who do not possess a telescope will use their eyes instead, and thus gain some knowledge of the wonders and beauties of the starry heavens. The knowledge thus acquired will stimulate their curiosity, and will give them a keener interest in reading books which describe the still greater wonders revealed by the telescope.

XXV.

RECENT ADVANCES IN ASTRONOMY.

THE study of astronomy is now making rapid strides. Greater progress is made in these days in a month than was achieved in former times in a year. Discovery now follows discovery in such quick succession, that books on astronomy very soon become obsolete and unreliable in their data, and it is only by the frequent issue of new editions that even popular works on the subject can keep up with the ever-growing mass of new knowledge which is being almost daily added to our store. Mere suspicions of yesterday become certainties to-morrow, and discoveries almost undreamt of occasionally startle even those whose knowledge of astronomy is something more than elementary.

This rapid advance in astronomical knowledge is chiefly due to two causes. First, the greatly increased interest now taken by the general public in the noble science, which has justly been called "sublime." Amateur astronomers have largely multiplied in number in recent years, and many of these are doing excellent work, even with small instrumental means. A remarkable instance of the interest taken in astronomy is afforded by the success attained by the British Astronomical Association. Started in the autumn of 1890, the number of its members had reached 800 before the close of 1893, a fact probably unique in the history of scientific societies. Other astronomical societies have also been recently founded, and the interest in the science seems to be rapidly spreading. This increased interest and desire to know more of the wonders of the heavens has naturally led to the second cause of the rapid increase of astronomical discoveries, namely, the construction of larger telescopes, and the invention of new methods of research. Some 50 years ago a refractor of 10 inches aperture was considered a large telescope, but now we have instruments with object glasses of 25, 30, and 36 inches aperture, and the construction of even larger telescopes is in contemplation.

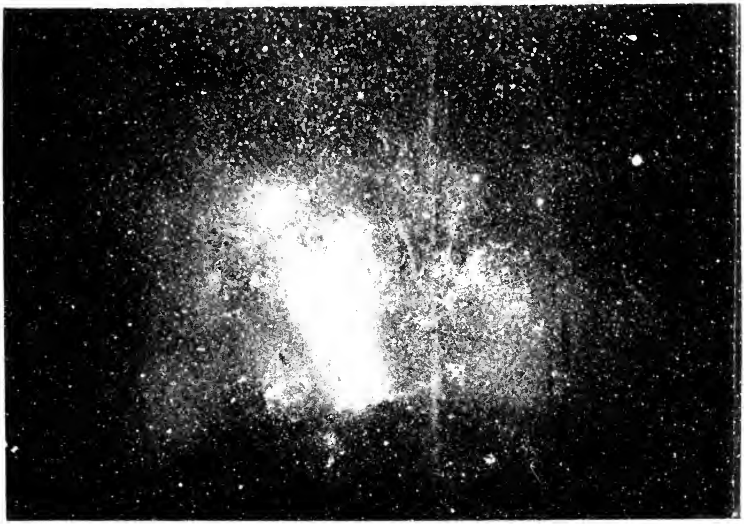
The application of photography to the heavenly bodies has caused quite a revolution in the study of astronomy. This is due to the introduction of the sensitive dry plates now generally used by photographers. Most successful results have been obtained in celestial photography by the Brothers Henry, at the Paris Observatory, by Dr. Common and Dr. Roberts in England, and others. An ordinary portrait lens strapped to a telescope driven by clockwork has also been successfully employed in photographing portions of the Milky Way, by Mr. Barnard, at the Lick Observatory, California; Mr. Russell, at the Sydney Observatory; and by Dr. Max Wolf, at Heidelberg. These are of great beauty, and give promise of still greater results in the near future. The stellar photographs taken at the Paris Observatory are especially beautiful, the stars appearing as small circular discs on a black background. Star clusters, nebulæ, and the great globular cluster in Hercules (13 Messier) have also been successfully photographed. Fine photographs of the great nebulæ in Orion have also been obtained by Dr. Common, Dr. Roberts, and Mr. Russell. These show a great extension of nebulous light. A wonderful photograph of the great nebula in Andromeda (31 Messier), by Dr. Roberts, shows that the "dark lanes" originally observed by Bond represent spaces between rings, into which the nebula is divided. These rings suggest a stage in the evolution of a stellar system on the lines of Laplace's Nebular Hypothesis.

Photographs of the Pleiades taken at the Paris Observatory, and by Mr. Roberts in England, show that all the brighter stars of the groups are involved in nebulous light. No less than 2326 stars can be counted on the Paris photograph.

The great nebula surrounding the curious variable star, Eta Argûs, in the Southern Hemisphere, was carefully observed by Sir John Herschel, during his residence at the Cape of Good Hope in the years 1834-38. He gives an elaborate and beautiful drawing of the nebula in his *Cape Observations.* The nebula has since been frequently observed by other astronomers, and suspicions have arisen that great changes have taken place in its appearance since Herschel's time. A photograph of the nebula has recently been obtained by Mr. Russell at the Sydney Observatory, which shows that "one of the brightest and most conspicuous parts of the nebula," near the centre of Herschel's drawing, has "wholly disappeared!" and its place is now occupied by "a great dark oval." Mr. Russell also finds that the portion referred to is now invisible in a telescope of 11½ inches aperture. That the photograph shows more than Herschel's telescope could possibly have done is proved by the fact that in the "lemniscate" or "key-hole" opening in the nebula, where Herschel saw *one* star, the photograph shows ten! The vanished portion of nebulous light was first missed by Mr. Russell in the year 1871, and the photographs now prove the correctness of his earlier observation. The accuracy of Sir John Herschel's drawing is shown by the fact that his descriptive paragraphs of other parts of the nebula "accurately describe the features as they are to-day," and leave no room for doubt that a remarkable portion of the nebula has actually disappeared since the date of his drawing. Mr. Russell has also photographed the "Magellanic

THE NEBECULA MINOR.

Taken by H. C. Russell, *October* 14*th*—15*th*, 1890.



THE NEBECULA MAJOR.

Taken by H. C. Russell, *October* 17*th*, 1890.

clouds." The larger cloud, the *Nubecula Major*, as it is called, he finds to be of a most complex form, with evidence of a spiral structure—a feature also traceable, but not so clearly, in a photograph of the *Nubecula Minor*, or smaller cloud. In these wonderful objects numerous small stars are seen to be mixed up with nebulous light. A photograph of the well-known "coal-sack," near the Southern Cross, shows that it is not completely devoid of stars, as its appearance to the naked eye might lead us to suppose. Numerous faint stars are visible in the photograph, and only near its northern border is there a spot completely free from stars. Photographs of the well-known Milky Way feature, "the gap in Argo," show that this apparent break in the course of the Galactic stream is "as thickly studded with stars and star dust as the neighbouring parts figured on the best star maps." It would therefore seem that the breaks and vacuities visible to the naked eye in the Milky Way are more apparent than real, and these photographs afford further evidence against the "cloven disc" theory of the Milky Way.

At the International Congress of Astronomers, referred to in a previous chapter, it was decided that a photographic chart of the whole heavens should be undertaken at several observatories, a portion of the sky being allotted to each. These charts will include all stars to the fourteenth magnitude. The preliminary arrangements for carrying out this plan are now nearly completed, and it is hoped that in a few years a complete chart of the heavens as they existed at the close of the nineteenth century will be available for the study of future generations.

The invention of the spectroscope, and its application to the study of celestial bodies by Dr. Huggins, has added greatly to our knowledge of the chemical constitution of the stars. By means of this wonderful instrument of research we can now analyze the light emitted by the Sun and stars, and by a comparison with the spectra of terrestrial substances we can ascertain the chemical elements which exist in the glowing photospheres of these distant orbs. A careful examination of stellar spectra has enabled astronomers to divide them into five types. The first of these shows the hydrogen lines abnormally dark. This type of spectrum is shown by Sirius and numerous other stars. The second type corresponds closely with the solar spectrum, in which many fine lines are visible, denoting the presence of metallic elements in the gaseous state. The third and fourth types include those in which dark bands are visible instead of fine lines. The number of stars with spectra of this type is comparatively small. They are mostly of an orange or red colour, and their chemical constitution is still somewhat uncertain. The fifth type includes the planetary nebulæ and some rare stars showing bright lines in their spectra. It was discovered by Dr. Huggins that the motion of a star in the line of sight, that is towards, or away from, the Earth, could be ascertained by observations of the displacement of the spectral dark lines when compared with the spectrum of a terrestrial substance such as hydrogen. Observations of this kind made at Greenwich Observatory and elsewhere gave very discordant results, owing to the extreme difficulty of accurately making such delicate measurements. This difficulty has now been overcome by measurements of the photographed spectra. Remarkable results have been obtained in this way by Professor Vogel, at Potsdam, the velocities of approach and recession being ascertained to a quite unexpected degree of accuracy. The measure must, of course, be corrected for the effect due to the Earth's orbital motion round the Sun, and so reliable are the results obtained from the photographs, that Mr. Keeler, the well-known American astronomer, has stated that he would undertake to determine the month of the year—if he did not know it—by spectroscopic observations of the great nebula in Orion! Indeed, it has been suggested that when this method of research has been further developed, it may be possible to reverse the process, and to ascertain from stellar spectra the earth's velocity in its orbit at any time, and hence the Sun's distance from the Earth, by a novel method.

A catalogue of the spectra of over 10,000 stars has recently been formed at the Harvard Observatory (U.S.A.). It is known as the *Draper Catalogue*, and was undertaken as a memorial to the late Dr. Henry Draper, who did much good work in this branch of astronomical research. The Catalogue was constructed from an examination of photographs of the stellar spectra, taken with a telescope of 8 inches aperture, having a focal length of 44 inches. For the brighter stars an exposure of at least five minutes was given to each plate, which contained two to four regions, 10° square. For the fainter stars an exposure of one hour was allowed to each plate of 10° square. The Catalogue includes stars down to 25° south declination. A more detailed examination of the spectra of the bright stars has also been made with the 11-inch telescope and 15-inch equatorial of the same Observatory. This latter research has led to some remarkable results. In the case of the bright stars Zeta Ursæ Majoris (Mizar) and Beta Aurigæ, the more conspicuous of the spectral lines are seen to be doubled periodically, indicating that these stars consist of two components revolving round each other, and so close that the highest powers of the largest telescopes are unable to separate them. Indeed, Professor Pickering has shown that "the effect of the prism may be regarded as multiplying the magnifying power of the telescope about 5000 times." Knowing the orbital velocity, we can easily compute the absolute dimensions of the stellar system in miles, and hence its mass in terms of the Sun's mass becomes known. By this new method we can, therefore, calculate the mass of a star the distance of which from the Earth is unknown![1]

Professor Pickering has recently discovered that the majority of the brighter stars in the Milky Way show spectra of the first or Sirian type, and, judging from the facility with which the smaller stars of the Galaxy impress their image on the photographic plate—indicating bluish light—he concludes that the fainter stars, which by their clustering produce the nebulous light of the Milky Way, have also, most probably, spectra of the Sirian stamp. From a careful enumeration of the stars in the *Draper Catalogue*, which lie on the Milky Way and its branches, as drawn by Heis, I find that out of 3061 stars, 1940 are of the first type, 1100 of the second or solar type, and the remainder of the third, etc. This gives a percentage of over 63 for stars of the Sirian type—a remarkable result. Possibly it may some day be shown that the rule is a general one, and that *all* the stars of the Milky Way have spectra of the first type, those showing spectra of other types being merely projected visually on the Galactic zone. If this be so, we may conclude that the Milky Way is not constituted in the same way as the rest of the sidereal universe, and has probably had a different origin—another argument against the "disc" theory.

It was long since suggested that the periodical

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[1] See chapter on 'Weighing the Stars.'

diminution of light in the famous variable star Algol was possibly due to the interposition of a dark eclipsing satellite. The correctness of this hypothesis has now been proved by a photographic examination of its spectrum by Professor Vogel, at Potsdam. He finds that before the minimum of light takes place, the brighter component is receding from the Earth, and after the minimum is past, it is approaching. In this case, as one of the components is a dark (or nearly dark) body, the spectral lines are merely shifted slightly in position, not doubled as in the case of Beta Aurigæ and Mizar. In these latter stars it appears that the plane of motion does not pass through the Earth, for, otherwise, there would be some decrease in the star's light when one component passed in front of the other. No such variation of light has been detected in either Mizar or Beta Aurigæ.

Discoveries in other branches of astronomy have also made rapid progress in recent years. The number of double stars has been largely increased, chiefly by the labours of that excellent observer, Mr. S. W. Burnham. Many of the interesting objects discovered by this accomplished astronomer already show signs of orbital motion, and the calculation of their orbits will, in the course of time, afford ample work for future computers. A number of orbits of binary stars have been recently calculated, and the number of these remarkable systems, for which more or less accurate orbits have been computed, now amounts to about 80. The faint companion of Sirius, which revolves round this brilliant star in a period of 50 to 60 years, has now approached so close to its primary, that it has passed beyond the reach of even the giant telescope of the Lick Observatory. It will, however, in a few years more, emerge from the rays of the bright star, and it will then be possible to compute its orbit with greater accuracy.

The number of known variable stars is also steadily increasing, and the fact that some of the long period variables show bright lines in their spectra, has been taken advantage of to detect some new objects of this class with the spectroscope. It should be noted, however, that large telescopes and photographic apparatus are not necessary for the discovery of variable stars, many of them having been found with an opera-glass or binocular. Four new variables have been added to the list by the present writer, by means of an ordinary binocular field-glass, similar to those used on race-courses. Variables of the Algol type are very rare, only ten altogether having been hitherto detected. As, however, the light of these variables only fluctuates for a short time near the minimum, the difficulty of detection may very possibly account for the small number known.

Professor Schiaparelli's observations of curious markings on the surface of the planet Mars, which he terms "canals," have been partially verified by other observers. Some, however, doubt their objective existence. The observations made at the opposition of 1892 are rather conflicting, and do not add very much to our knowledge of the planet.

Schiaparelli's supposed discovery that the rotation periods of Mercury and Venus are the same as their periods of revolution round the Sun has not yet been fully confirmed by other observers. Indeed, in the case of Venus, M.M. Niesten and Stuyvaert, of the Brussels Observatory, find that a period of about $23\frac{1}{3}$ hours, originally found by de Vico, will suit their observations very well. The observations are, however, of great difficulty, owing to the faintness of the markings visible on these planets, and the peculiar position of the planets themselves with reference to terrestrial observers.

The discovery of minor planets between Mars and Jupiter still continues. Only 13 of these small planets were known in the year 1850. The number reached 100 in 1868, 200 in 1879, 300 in 1890, and now (Feb. 1894) over 380 have been discovered. It would seem that the number of these small planets is probably very large, and it will soon become a difficult matter to keep an accurate account of them. For instance, a supposed new planet found by Palisa on August 14th, 1891, afterwards proved to be identical with Medusa (No. 149), which was discovered by Perrotin in September 1875, and several other similar cases have recently occurred.

On September 9, 1892, Prof. E. E. Barnard, observing with the 36-inch refractor of the Lick Observatory, made the remarkable and unexpected discovery of a fifth satellite to the planet. It is nearer to Jupiter than the other known satellites, and revolves round the planet in a period of 11 hours, 57 minutes, 22½ seconds, at a mean distance of 112,500 miles from the centre of its primary; or about 67,000 miles from the surface of Jupiter. The new satellite is a faint object even in large telescopes, and its diameter does not probably exceed 100 miles.

The supposed duplicity of Jupiter's first satellite, suspected by Messrs. Barnard and Burnham at the Lick Observatory, in September 1890, has not been confirmed. Mr. Barnard now considers the appearance as probably due to a white belt on the surface of the satellite, nearly parallel to the belts of Jupiter. When the satellite transits a bright portion of Jupiter's surface, this bright belt becomes invisible, and the other portions of the satellite appear like two dusky spots, thus giving the satellite the appearance of being double. Further observations will be necessary to prove the accuracy of this hypothesis, but that the satellite is really double would seem very improbable. Later observations of this satellite by Professors Campbell and Schaeberle of the same Observatory, show that it is "ellipsoidal, with one of its longer axes directed towards the centre of Jupiter."

An interesting observation of an eclipse of Saturn's satellite, Japetus, in the shadow of the globe and rings of the planets, was made by Mr. Barnard at the Lick Observatory on November 1st, 1889. He says —"The observations show that after passing through the sunlight shining between the ball and rings, Japetus entered the shadow of the crape ring. As it passed deeper into this, the absorption of sunlight became more and more pronounced, until finally the satellite entered the shadow of the bright rings. In a word, then, the crape ring is truly transparent, the sunlight sifting through it. The particles composing it cut off an appreciable quantity of sunlight. They cluster more thickly, or the crape ring is denser, as it approaches the bright rings." From the total disappearance of the satellite when it passed behind the bright ring, he concludes that "the bright ring is fully as opaque as the globe of *Saturn* itself."[1]

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[1] *Monthly Notices*, R.A.S., January 1890.

XXVI.

SOME ASTRONOMICAL ERRORS AND ILLUSIONS.

ALL books contain some errors—either misprints, or mistakes due to oversights, or imperfect knowledge of a special subject. No man's work is perfect. Misprints seem sometimes unavoidable, even when the greatest care is taken in the correction of proof sheets; but these are easily detected, and are not of so much importance as errors in the statement of facts and principles. These latter are of course very misleading to the student of astronomy, and in the interests of truth should not, I think, be allowed to pass uncorrected. It may, perhaps, seem rather insidious to call attention to mistakes in other men's work; but as some of the errors referred to, unfortunately, occur in my own writings, I have less hesitation in making the necessary corrections, the accuracy of which may be tested by reference to the authorities quoted.

Proctor's works are generally very accurate, and free from error. I have, however, found a few trivial mistakes, which, although they do not detract from the value of his excellent writings, should, I think, be corrected. In the article on 'Coloured Suns,' in his valuable *Essays on Astronomy*, he speaks of the components of the beautiful double star ϵ Boötes as "nearly equal" in brightness.[1] In reality, however, they are rather unequal, the magnitudes being about 3 and 7,[2] a difference which implies that the primary star is nearly forty times brighter than its companion. In his article on 'A Novel Way of Studying the Stars,' in the same volume, Proctor estimates the area of the heavens covered by the Milky Way as one-tenth of the Northern Hemisphere, and one-eleventh of the Southern. This may be correct enough for the very diagrammatic representation of the Galaxy given in most popular star atlases; but in Heis's more carefully drawn delineation, I find that the Milky Way covers about one-fourth of the Northern Hemisphere. The southern half of the Galaxy, as drawn by Dr. Gould in the *Uranometria Argentina,* is of still greater extent, covering, according to Markwick, about one-third of the Southern Hemisphere.

In his interesting little work *Half-Hours with the Telescope*, Proctor says that all four satellites "are visible in a good opera-glass";[3] but probably they could only be seen with such an instrument by those gifted with exceptionally keen eyesight. In

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[1] The star is, however, correctly described in his *Half-Hours with the Telescope.*

[2] Webb's *Celestial Objects*, 4th edition, p. 243.

[3] p. 85.

any case, atmospheric conditions would have much influence on their visibility, even in a powerful binocular. In describing Orion in the same volume, he speaks of Betelgeuse (α Orionis) "as one of the most remarkable variables in the heavens." This is, however, incorrect, as the star remains for long periods constant in light, or nearly so; and even to a careful observer of variable stars, it often continues for months together without perceptible change. Its variation, even when most conspicuous, is small, and might easily be overlooked by an ordinary observer.

It was recorded by Hevelius that the famous variable star Mira (o) Ceti was invisible in the years 1672 to 1676. From this it was inferred that the star did not rise to a maximum in those years, and this statement has been repeated in several text-books of astronomy. The idea is, however, quite incorrect; for it was long since (1837) pointed out by Bianchi[1] that the supposed invisibility of Mira in the years referred to by Hevelius was simply due to the fact that the maxima in those years occurred at a time when the star was near the Sun, and could not be observed. In fact, as the period from maximum to maximum is about 331 days, eleven periods will be nearly equal to ten years. Hence if the star, in any particular year, happens to be at a maximum when near the Sun (in April), it will be in nearly the same position when at maximum

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[1] *Astronomische Nachrichten.*

after an interval of ten years. Hence, roughly speaking, the star's maximum will be invisible every ten years. Of course for a year or so before and after this time it will be too close to the Sun for observation; and hence the maxima will pass unnoticed for several years—at least to ordinary observers. The non-appearance of Mira in the years 1672—1676 is therefore satisfactorily explained. In several books on astronomy it is stated that Mira wholly disappears at minimum. This, however, is quite incorrect. The star never descends below magnitude 9½, and when favourably placed for observation, may always be seen in a telescope of three inches aperture.[1]

With reference to the variable star Algol, it is sometimes stated that the period is increasing; but, on the contrary, it is still *diminishing*, as Chandler's investigations have clearly shown. It is also frequently stated that the variation of light is from magnitude two to magnitude four; but at its brightest, the star is always a little fainter than an average star of the second magnitude, and at minimum it never descends so low as the fourth magnitude. The total variation certainly does not exceed one and a half magnitude, and Professor Pickering's photometric measures at Harvard College show that it does not much exceed one magnitude. My own observations agree with Professor Pickering's result.

The remarkable variable χ Cygni has been often

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[1] Chandler's *Catalogue of Variable Stars.*

confused with Flamsteed's χ or 17 Cygni; but the latter is quite a distinct star. The variable is the true χ Cygni of Bayer, and Flamsteed affixed the letter χ to his number 17 of Cygnus by mistake, the variable having been faint at the time of his observation. Stone proposed to call 17 χ^1, and the variable χ^2; but there seems to be no necessity to perpetuate an error which has long since been pointed out. All authorities on variable stars now give this variable its correct designation—χ Cygni.

With reference to the apparent motions of the planets in the sky, it is stated in some works on astronomy that a planet is *stationary* when it is moving in a line directed towards an observer on the Earth. Professor Lockyer says, "the planet, as seen from the Earth, will appear at rest as we are advancing for a short time straight to it"; but this is quite incorrect; on the contrary, when in this position it has a *rapid* direct motion.[1] Herschel and other astronomers give the correct explanation of the stationary points.

With reference to the apparent motion of the binary or revolving double stars, as seen from the Earth, the idea seems a not uncommon one that the minimum distance between the components *always* occurs when the companion star is at the periastron of the *real* orbit. Some years since a well-known astronomer expressed his opinion that the famous southern binary star α Centauri had not then reached the

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[1] *Sidereal Messenger*, May 1889, p. 233.

periastron, *because* the components had not yet arrived at their point of nearest approach. But this is quite a mistake. As a general rule, the minimum distance does *not* occur at the periastron point. Under certain conditions, of course, the minimum apparent distance may coincide with the periastron, but usually this is not the case. From my experience in the calculation of binary star orbits, it will, I think, be admitted that I am qualified to speak with some authority on this point; and I feel confident that my contention will not be disputed by any one who really understands the subject.

In some books on astronomy it is stated that the temporary star of 1866 in Corona Borealis—the "Blaze Star," as it is sometimes called—was discovered simultaneously by several observers; but as is well known, the star was really discovered by the late Mr. Birmingham, at Tuam, Ireland, at midnight on the night of May 12 in that year. In his work, *L'Origine du Monde*, M. Faye, the French astronomer, has the following misleading statement—"Le cas le plus frappant et le mieux observé est celui de 1866. M. Courbebaisse, ingénieur des pont est chaussées, vit un soir (13 mai) briller dans la Couronne boréale une belle étoile qu'il n'avait pas remarquée les jours précédents," and he does not mention Mr. Birmingham! That the star was seen on the night of May 13 may perhaps be true; but it was certainly *first* seen by Mr. Birmingham on the *preceding* night, and to him all authorities on variable stars unanimously award the discovery. This is not a question of Adams or Leverrier, and Neptune; the credit of the discovery is undoubtedly due to the Irish astronomer, and to him alone.

In the fourth edition of *The Heavens*, by Guillemin, it is stated with reference to Betelgeuse, that this bright star "has recently descended to the sixth magnitude."[1] This is, however, quite erroneous. The star—although certainly variable to a small extent—has never, so far as I know, been observed as faint as even the second magnitude. The extreme range of variation does not probably exceed half a magnitude. I have never seen it myself fainter than Aldebaran, and it usually exceeds that star in brightness.

I will now notice some errors in my own writings. In my *Planetary and Stellar Studies* it is stated that Tycho Brahé's star of 1572 "increased rapidly in brilliancy"[2] after its discovery; but this would seem to be a mistake. The star more probably appeared suddenly at its *full* brightness. In p. 148, the discovery of the temporary star of 1604 is attributed to Möstlin; but it was really discovered by Brunowski, a pupil of Kepler's, on October 10 of that year. Möstlin was Kepler's old master, and also observed the star, but did not see it well till October 16. In the chapter on 'Stellar Photography' it should have been stated

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[1] p. 271.

[2] p. 147.

that the "three separate stellar photographs"[1] are taken on the *same* plate, the plate being slightly shifted at the second and third exposures, so as to make each star finally appear in three small discs, forming an equilateral triangle. In the note at p. 244 of the same volume, in the passage, "the great inequality in the motion of Jupiter and Saturn depends on the exact equality, etc.," the word should be *approximate*, not "exact."

In *The Scenery of the Heavens*[2] it should have been stated that Secchi was probably mistaken when he thought he could see bright lines in the spectrum of the variable R Geminorum. A subsequent careful examination of the star's light by Vogel showed the spectrum to be really due to carbon, and not to hydrogen. At p. 117, the discovery of the great comet of 1680 is ascribed to Halley, whereas G. Kirch was the real discoverer. On p. 44 the length of the "Hyginus cleft" on the Moon is given as nine miles instead of ninety; and there are a few other misprints.

Many telescopic observations have been made from time to time—even by skilled observers—which other observers have been unable to verify. The weight of evidence against the reality of these observations is so strong that we are compelled to consider them as optical illusions, due either to some peculiarity in the observer's eye, or to some defect in

[1] p. 213.

[2] p. 258.

the telescope employed. A short account of some of the most remarkable of these cases may prove of interest to the general reader.

From irregularities in the observed "proper motion" of the bright star Procyon, astronomers came to the conclusion that probably its motion was disturbed by the attraction of a close companion—as in the well-known case of Sirius. In 1873 the great Russian astronomer, Otto Struve, believed that he could see a faint companion to this brilliant star. Every precaution was taken to prevent illusion, and to test the accuracy of the discovery. The position of the faint star was even measured by Struve and his assistants! In 1874 the companion was again observed by Struve, and its position was found to agree closely with that deduced by Dr. Auwers from theoretical considerations. Other Russian astronomers thought they could see it also, and it was even measured by one observer in England. The Washington observers, however, failed to see it with their great 26-inch refractor. At last Struve himself announced that his supposed companion was merely an optical illusion, or "ghost," as these imaginary telescopic stars are called by astronomers. Mr. Burnham examined Procyon in October 1888, with the great Lick telescope, and says, "Carefully examined with all powers up to 3300 on the 36-inch under favourable conditions. Large star single, and no near companion."

In 1863, Goldschmidt, observing with a telescope of only 4 inches aperture, announced the discovery of five faint stars within 1′ of arc of Sirius. Dawes saw one of these, but failed to see any of the others. Secchi, however, in 1865, found a companion at 44″ distant, and Marth, at Malta, another at about 70″. Burnham with the Lick telescope found the well-known close companion a "very easy object" in 1888, and adds, "I have carefully looked for other stars near Sirius, but without finding anything worth noting." Some of Goldschmidt's companions must therefore have been "ghosts."

The Pole star has a small companion of the ninth magnitude, which forms a well-known test for small telescopes. In the year 1869, M. A. de Boë, a well-known Belgian astronomer, announced his discovery of two faint stars nearer to the bright star than the companion. Other observers thought they could also see these faint attendants, but the great telescope at Chicago failed to reveal their existence to Burnham, who said—"I have no hesitation in saying these supposed stars do not exist." Observing with the giant telescope of the Lick Observatory in April 1889, Burnham says—"Carefully examined with the 36-inch with all powers. Both stars single, and no companion nearer than the Struve star." We may therefore safely conclude that M. de Boë's supposed stars were mere optical illusions.

A supposed companion to the fourth magnitude star, 72 Ophiuchi, probably forms another example of a telescopic "ghost." It was discovered as a double star, or supposed double star, by Otto Struve, on November 1, 1841, the companion being rated of the seventh magnitude, but it was seen single on May 14, 1842. It was again seen double in September 1842, but was observed to be single in the years 1844, 1848, 1850, 1851, 1852, and 1859. In 1876, however, Struve again saw the companion very distinctly, and measured its position with reference to the brighter star. He concluded that the star was really double, but that the companion was subject to great fluctuations of light. It was measured by Mädler in 1845 and 1847, and in 1859 Secchi found the components well separated only three weeks before it was found single by Struve at Poulkova! On two very fine nights in 1874, Professor Newcomb could not see any trace of the companion with the 26-inch refractor of the Washington Observatory, and Professor Hall was equally unsuccessful in 1876. Burnham found it "certainly single" on "a first-class night" in 1880, with an 18½-inch refractor, and observing the star with the great Lick telescope in April 1889, he says, "Large star, single, with 36-inch, and no near companion."

Sir William Herschel, observing Saturn in the year 1805, thought that the ball of the planet was not only flattened at the poles—as it is known to be—but also occasionally at the equator, giving the planet a "square-shouldered" aspect. Proctor attempts to explain this appearance by an optical illusion, produced by the different curvature of the ball and rings, but admits that the phenomenon may possibly have an objective reality due, perhaps, to physical changes in the planet's atmosphere, which is probably of considerable depth. As Herschel verified his observations with different instruments and by actual measurement, and as the same phenomenon has been noticed by other observers, it does not seem quite certain that it was merely due to an optical effect.

Sir W. Herschel thought he could see six satellites to the planet Uranus. These, with the two inner ones, Ariel and Umbriel, discovered in 1847, would make eight in all, but the large telescopes of modern times fail to show more than four. Some of those seen by Herschel must, therefore, have been either optical "ghosts," or else small fixed stars which happened to lie near the planet's path at the time of observation. Herschel also suspected, at one time, that he could see traces of rings round Uranus like like those round Saturn, but his observation was never confirmed, either by himself or other observers, and we now know that this planet has no such appendage.

Lassell and Bond thought they could see traces of a second satellite to Neptune, but this suspicion has never been confirmed.

When Venus is in the crescent form, or near inferior conjunction, many observers have thought that they could see the dark portion of the disc in the same way that the dark part of the Moon is visible when only a few days old, "the old Moon in the young Moon's arms," as it is popularly called. This phenomenon is easily and satisfactorily explained in the case of the Moon by sunlight reflected from the Earth, but is so unaccountable in the case of Venus, as a moment's consideration will show, that some astronomers have attributed the appearance to an optical illusion. The phenomenon was, however, observed so far back as 1715, and it has often been seen in recent years by such excellent observers as Browning, Elger, Erck, Franks, Grover, Webb, and Winnecke. It was seen by Franks and Perkins in 1884; darker than the sky by the former observer, and brighter than the sky by the latter. Another observer, Mr. J. M. Offord, described it as of "a prussian-blue colour." It is even said to have been seen in the daytime by Andreas Mayer in October 1759, and by Winnecke in 1871. As an attempt at a solution of the mystery, a comparison has been suggested with some of our terrestrial nights, which are much brighter than others, due to a phosphorescent glow over the whole sky, which has been noticed by Arago, Schröter, Webb, and by the present writer both in this country and in India. It must be admitted, however, that the hypothesis is not a plausible one, and does not give a very satisfactory explanation of this puzzling phenomenon.

Several observations have been recorded of a supposed satellite of Venus, but it has now been clearly proved that these were due either to imperfections in the telescope used, or to small stars near which the planet passed in its course.

XXVII.

THE ARITHMETIC OF ASTRONOMY.

IN works on astronomy, numerical results are usually given with reference to the distances of the Sun, planets, and fixed stars, their diameters, densities, etc., but no attempt is made—at least in popular works—to explain to the general reader the method of calculation by which these results have been arrived at. On making inquiry from those qualified to give information on the subject, the reader will probably be told that the calculations are too complicated to admit of popular explanation, but that the figures may be accepted as undoubtedly correct. This may possibly satisfy the reader who is not versed in figures, but to those who have received at least the elements of a mathematical education, the reply will not be a satisfactory one. They will probably desire to know something more of the methods by which the results have been obtained, or at least how the figures given in the text-books have been found from the measurements derived from the observations. It has, therefore, occurred to me that an elementary account of the methods by which these figures are found may prove of interest to those who are familiar with the elements of mathematics. I do not propose to describe here the methods of observation employed to determine the numerical results, but merely to show how these figures are found from the observational data.

To begin with the most important of these numbers, the Sun's distance from the Earth, we often hear of the Sun's "parallax," that its probable value is 8·8″ of arc, and that the resulting mean distance of the Sun is nearly 93,000,000 miles. What is the meaning of these statements? I will not here enter into the methods of observation by which the value of the "solar parallax" is measured. But, supposing this parallax to be 8·8″, what is the meaning of the statement, and how are we to obtain from it the Sun's distance from the Earth? Those who are familiar with the first principles of Trigonometry will know that the angle subtended by an arc equal in length to the radius of the circle is 206,265″. One foot, therefore, on the circumference of a circle of 206,265 feet radius, will subtend an angle of 1″ at the centre of the circle, and 8·8 feet an angle of 8·8″. Now the Sun's "parallax" is the angle in seconds of arc which the Earth's equatorial semi-diameter, or radius, subtends at the centre of the Sun, when the Earth is at its mean distance. As the equatorial diameter of the Earth is about 7926 miles, its radius will be 3963 miles. Hence we have the following simple proportion for finding the Sun's distance—

8·8 : 206,265 : : 3963 : Sun's distance

—whence

$$\text{Sun's distance} = \frac{206,265 \times 3963}{8 \cdot 8} = 92,889,567 \text{ miles.}$$

To find the Sun's diameter, we know from observation that, at the Sun's mean distance, the diameter measures 31′ 3·6″, or 1923·6″ of arc. Hence we have the proportion—

206,265 : 1923·6 : : 92,889,567 : Sun's diameter.

Hence

$$\text{Sun's diameter} = \frac{92,889,567 \times 1923 \cdot 6}{206,265} = 866,275 \text{ miles.}$$

To find what the Sun's density (or specific gravity) is, with reference to that of the Earth, we know from the principles of Geometry that the volumes of spheres are proportional to the cubes of their diameters. Taking the Sun's diameter in round numbers at 866,000 miles, and that of the Earth at 7912 miles, we have the volumes as—

$$(866,000)^3 : (7912)^3$$

Working this out, we find that the Sun's volume is equal to 1,311,400 times that of the Earth. But it has been found from mechanical principles that the

Sun's mass is only 327,214 times the mass of the Earth. Hence its density must be—

$$\frac{327{,}214}{1{,}311{,}400} = 0{\cdot}2495$$

—that of the Earth being represented by 1.

If we take the Earth's specific gravity at 5·6, that of the Sun will be

$$5{\cdot}6 \times 0{\cdot}2495 = 1{\cdot}3972 \text{ (water} = 1) = 1{\cdot}40 \text{ nearly.}$$

The latest determination of the speed at which light travels through space gives a velocity of 186,337 miles a second. Hence to find the time taken by light to reach us from the Sun, we have merely to divide the Sun's distance by this velocity, or—

$$\text{Time in seconds} = \frac{92{,}889{,}567}{186{,}337} = 498 \text{ seconds}$$

—or 8 minutes, 18 seconds.

When we speak of the "parallax" of a fixed star, the word "parallax" has not exactly the same meaning as in the case of the Sun's distance. Here our base line of measurement is not the Earth's radius, but the radius of the Earth's orbit round the Sun, or the Sun's mean distance from the Earth. The parallax of a fixed star is then the angle which the radius of the Earth's orbit subtends at the star. The angle which is *actually measured* is of course the angle subtended by the *diameter* of the Earth's orbit, and is double the star's annual parallax. Hence for a star with an annual parallax of 1″ of arc, the distance from the Earth would be—

92,889,567 × 206,265 = 19,159,866,537,255 miles,

or about 19 billions of miles.

There is, however, no star—as far as we know at present—with a parallax so large as 1′ of arc. The parallax of the nearest—Alpha Centauri—is about three-fourths of a second. Therefore to obtain its distance, we must divide the above result by $\frac{3}{4}$, or multiply by $\frac{4}{3}$. This gives—

25,546,488,716,340 miles,

or about 25½ billions of miles for the distance of Alpha Centauri.

To find the time taken by light to travel from this star to the Earth, we must divide the above number by 186,337, as before. This gives 137,098,315, or 4·344 years, or about 4 years and 4 months.

This calculation leads us to a simple expression for finding the light journey from any star in years when its parallax is known. For we see that the distance for a parallax of 1″ had to be divided by the measured parallax, and again by the velocity of light, and by the number of seconds in a year, which is—

$365\frac{1}{4} \times 24 \times 60 \times 60 = 31{,}557{,}600.$

Hence if we call the parallax of the star p, we have—

$$\text{Light journey in years} = \frac{19,159,866,537,255}{31,557,600 \times 186,337 \times p} = \frac{3{\cdot}258}{p}$$

For a parallax of one-tenth of a second the light journey would therefore be 32·58 years. This is about the parallax ascribed to the star 1830 Groombridge, which has a proper motion of about 7″ of arc per annum. Let us see what this velocity will give. With a parallax of one-tenth of a second, the distance travelled in one year will be 7″ divided by $\frac{1}{10}$, or 70 times the Sun's distance from the Earth. Hence the velocity will be—

$$\frac{92,889,567 \times 70}{31,557,600} = 206 \text{ miles a second.}$$

Arcturus, with a proper motion of 2·26″ of arc annually, has a parallax, according to Glasenapp, of only 0·018 of a second. This gives the enormous velocity of 368 miles per second. In general, the velocity may be simply obtained by multiplying the proper motion by 2·943, and dividing by the measured parallax. The velocities found in this way represent the star's motion on the background of the sky, or at right angles to the line of sight. There may also be —and generally is—motion *in* the line of sight, to or from the eye, but this can only be ascertained by the spectroscope.

It may interest some readers to know how the mass of a binary or revolving double star is found in terms of the Sun's mass. In my *Planetary and Stellar Studies* I have given a formula for calculating the combined mass of the components of a binary star when the elements of the orbit and the star's parallax are known. The computation is a very simple one. Let us take the case of the binary star 70 Ophiuchi, for which I have computed an orbit, and find a period of 87·84 years (a period which has been confirmed by Burnham), with a mean distance between the components of 4·5″ of arc. Now Kruger found a parallax of 0·162 of a second, and hence—

Mean distance between components $= \frac{4·5}{0·162} = 27·77$ times the Sun's distance from the Earth, and

Sum of masses of components $= \frac{(27·77)^3}{(87·84)^2} = 2·77$ times the mass of the Sun.

The rule expressed in words is—Divide the mean distance between the components by the parallax. Cube the quotient, and divide by the square of the period in years, and the result will give the sum of the masses of the components in terms of the Sun's mass, taken as unity.

In astronomical works we find the force of gravity on the Sun and planets stated in terms of gravity at the surface of the Earth. If we know the relative masses of the two bodies, this is easily calculated. Let us take the case of the Sun and Earth. The mass of the Sun is, as stated above, 327,214, if that of the Earth be taken as 1. Now it is a well-known principle that the mass of a sphere acts on a body at its surface as if the whole mass of the sphere were concentrated at the centre of the sphere. Its action will also be inversely as the square of the distance from the centre, or as the square of the radius. Hence we have—

$$\text{Force of gravity at Sun's surface} = \frac{327{,}214 \times (3963)^2}{(433{,}000)^2}$$
$$= 27{\cdot}41.$$

Hence a body which would weigh 1 pound at the Earth's equator, would weigh 27·41 lbs. if transferred to the surface of the Sun.

The force of gravity at the surface of all the planets and satellites may be calculated in a similar way.

XXVIII.

THE MYTHOLOGY OF THE STARS AND PLANETS.

MANY of the names of the constellation figures and those of all the larger planets are evidently derived from the ancient mythology of Greece and Rome. A short account of the origin of these names may prove of interest to the reader. We will first take the constellations in alphabetical order.

Andromeda (the Chained Lady) was the daughter of Cepheus, King of Ethiopia, and his wife Cassiopeia. To assuage the wrath of Neptune, who—instigated by the jealousy of the sea-nymphs for the vaunted beauty of Cassiopeia—had sent a great sea monster to ravage the whole country of Ethiopia, Andromeda was chained to a rock on the sea-shore, and was saved from destruction by Perseus, who, returning from the slaughter of the Gorgons with the head of Medusa, turned the monster into stone, and married Andromeda.

Aquarius (the Water-Bearer) is one of the twelve signs of the Zodiac, and has been represented from ancient times as a man pouring water from a vase.

Aquila (the Eagle, Flying Vulture, or Flying Grype) formed one of the asterisms of Hipparchus. Its brightest star, Altair, derives its name from the Arabic word *el-taïr*, the flying eagle.

Argo (the ship Argo). This large southern constellation formed one of the original 48 constellations. It represents the ship which conveyed the expedition in search of the Golden Fleece. Its brightest star, Canopus, is second only to Sirius in brilliancy, but does not rise above the English horizon.

Aries (the Ram) represents the Golden Fleece which the Argonautic expedition went in search of. Some, however, have attempted to identify it with the ram sacrificed by Abraham on Mount Moriah; but this seems very fanciful. Aries forms one of the twelve signs of the Zodiac.

Auriga (the Charioteer or Waggoner) formed one of the original 48 constellations, and is thought by some to be the Horus of the Egyptians, but this seems doubtful. The brightest star, Capella, with ϵ, ζ, and η form the goat Amalthea, Jupiter's nurse. Capella has been called "The Shepherd's Star," a term which has also been applied to the planet Venus.

Boötes (the Herdsman). According to Grecian mythology, Boötes was the son of Jupiter and Callista. He was a great hunter, and one day while on the chase he met a bear, which proved to be his mother transformed into this shape by Juno! When about to kill the bear, Jupiter intervened and transferred them both to the sky. Arcturus, the brightest star of the constellation, was well known to the ancient mariners, and its name appears to be derived from two words signifying "the bear's tail." It seems to have been the first star observed in daylight with the telescope—by Morin in 1635. The Arcturus mentioned in Job probably refers to the Great Bear.

Cancer (the Crab). This is one of the original 48 constellations, and is said to represent a crab which was raised to the skies because it pinched the toes of Hercules in the Lernæan marsh! In some old star maps it is represented as a crayfish or lobster. Cancer forms one of the signs of the Zodiac.

Canis Major (the Great Dog) formed one of the ancient 48 constellations. Its brightest star, Sirius, derives its name from the Greek word *Σείριος*, and it was worshipped by the Egyptians under the name of Sothis (Horus), Anubis, and Thoth. Some consider it to be the *Mazzaroth* of Job. Sirius was also supposed to be Orion's hound, and may perhaps be identical with the Cerberus of the Greeks.

Canis Minor (the Little Dog) also formed one of the original 48 constellations, and was called *Προκυων*, the precursor, because it appeared in the morning sky before Sirius. The name survives in Procyon, its brightest star.

Capricornus (the Sea Goat). This is also one of the old 48 constellations, and was supposed to represent the plunge of the god Pan into the Nile. Pan is said to have been the son of Mercury and Penelope, and was represented as half man and half goat. Capricornus forms one of the signs of the Zodiac.

Cassiopeia (the Lady in the Chair) was the wife of Cepheus, to whom the adjoining constellation is dedicated. She is represented as bound to a throne or chair formed by the five well-known stars arranged like a W.

Centaurus (the Centaur) is a southern constellation, and probably derives its name from the fabled centaurs of mythology, who were half men and half horses.

Cepheus (the Monarch), King of Ethiopia. He was the husband of Cassiopeia, and father of Andromeda.

Coma Berenices (Berenice's Hair) is stated by Conon to represent the tresses of a lady placed in the heavens as a reward for a lock of hair which—on account of a victory won by her husband—she had dedicated to Venus.

Corona Borealis. According to Plutarch this represents a crown given by the god Bacchus to his wife Ariadne.

Corvus (the Crow), supposed by some to represent the raven sent out by Noah from the ark.

Cygnus (the Swan). This fine constellation, one of the glories of the Northern sky, formed one of the original 48 asterisms. Its principal stars form a fairly regular cross, and hence it was called *Christi* *crux* by Schickard and others in the eighteenth century.

Delphinus (the Dolphin). One of the original 48 constellations. According to some of the ancient writers it represents Apollo bringing Castalius from Crete. Others suppose it to have been the dolphin which carried Arion. Novidius, however, saw in it the fish which swallowed Jonah!

Draco (the Dragon), which guarded the golden apples in the garden of the Hesperides, and was killed by Hercules. Some, however, think it typical of the serpent which tempted Eve!

Eridanus (the River). Some suppose this represents the Nile, others say the Po, or the Granicus, or the Euphrates. It has also been called the River of Orion. Eridanus lies to the south-west of the highest point attained by the Sun on the longest day; and this may have some connection with the fable of Phaeton, who, after driving the chariot of the Sun, was struck dead by Jupiter, and fell into the river Eridanus. The brightest star of this constellation is Achernar (the end of the river). It does not rise above the English horizon.

Gemini (the twins), Castor and Pollux, sons of Jupiter and Leda. They accompanied Jason in his expedition in search of the Golden Fleece, and were conspicuous for their bravery. Jupiter made Pollux immortal, but not Castor. When Castor was slain by Lynceus, Pollux shared his immortality with his brother, and they lived and died alternately. They were finally placed in the sky, and changed into the two bright stars which now bear their names. Gemini forms one of the signs of the Zodiac.

Hercules, the great hero of mythology, was supposed to be the son of Jupiter by Alcmene, wife of Amphytrion. Hercules possessed great strength and courage, and his twelve labours are familiar to students of the classics. One of these labours was the destruction of the dragon which guarded the garden of the Hesperides (see *Draco*). Hercules formed one of the 48 ancient constellations. It is of considerable extent, but includes no star brighter than the third magnitude.

Hydra. Supposed to represent the Lernæan serpent. It was said to have had 50 heads, and that when one was cut off many others were produced in its place. It was finally killed by Hercules.

Leo (the Lion). Supposed to represent the Nemean lion killed by Hercules. Stower, however, in 1386, thought it represented one of Daniel's lions ; and it was considered by Schickard as typical of " the Lion of the tribe of Judah." Its brightest star, Regulus, has been called the royal star.

Lepus (the Hare) was one of the original 48 constellations. The right foot of Orion rests on Lepus.

Libra (the balance). One of the signs of the Zodiac. According to some writers this constellation was formed by the Alexandrian astronomers ; but others say it was raised to the memory of Julius Cæsar. It seems to have been known to Ovid, Pliny, Virgil, Vitruvius, and other ancient writers.

Lyra. Supposed to represent the lyre of Orpheus, a famous Grecian poet who accompanied the Argonautic expedition in search of the Golden Fleece. Novidius, however, saw in it the harp of David, and Schiller supposed it to represent the manger of Bethlehem ! It formed one of the original 48 constellations. Its brightest star, Vega, is one of the most brilliant in the heavens.

Ophiuchus (the Serpent Bearer) is one of the old 48 constellations, and is supposed by some to represent one of Hercules' victories. It has been called Serpentarius.

Orion (the Heavenly Hunter) was said to have been the son of the god Poseidon and Euryale, daughter of Minos. According to some, however, his mother was Alcyone, one of the Pleiades. Orion was said to have been an attendant on the goddess Diana (or Artemis). Having one day insulted his mistress, he was either killed by a scorpion, or shot by the goddess herself, and was then placed among the stars. Orion was worshipped in Egypt under the name of Osiris. He has also been identified with the Nimrod of Scripture (Genesis x. 8, 9). Homer speaks of Orion marrying Aurora, goddess of the Dawn. The fable of his having been killed by a scorpion probably refers to the disappearance of Orion in the west when the constellation of the

Scorpion appears above the eastern horizon. Some suppose that Adonis (Tammaz) was identical with Orion. Merodach, the god of Babylon, seems to have been Orion under another form. Orion is mentioned by Job, Ezekiel, and Amos.

Pegasus (the Winged Horse) is supposed to represent Apollo's horse, but by others the horse of Nimrod.

Perseus (the rescuer of Andromeda) was the son of Jupiter and Danae. This constellation formed one of the 48 original asterisms, but according to Schickard's innovations it represents David with the head of Goliath!

Pices (the Fishes). This also formed one of the old 48 constellations. It is supposed to represent two fishes with their tails tied together with a cord. It is one of the signs of the Zodiac.

Sagitta (the Arrow). Small as this constellation is, it formed one of the ancient 48. It lies between Aquila and the head of Cygnus.

Sagittarius (the Archer) is usually represented as a figure like the ancient centaurs, who were fabulous creatures, half man and half horse. It has, however, sometimes been drawn as a satyr. It is one of the twelve signs of the Zodiac.

Scorpio (the Scorpion). This was one of the original 48 constellations, and may perhaps represent the scorpion which killed Hercules. It forms one of the signs of the Zodiac. Its brightest star, Antares, is so named from the Greek words meaning "redder than Mars."

Serpens (the Serpent). This also formed one of the old 48 asterisms. It was called by the Greeks Οφις. It is usually represented in star maps as a serpent in the hands of Ophiuchus.

Taurus (the Bull) is supposed by some to represent the bull under the form of which Jupiter swam away with Europa. It is one of the twelve signs of the Zodiac. Its brightest star, Aldebaran, is a reddish star of the first magnitude, and is so named from two Arabic words signifying "the hindmost," as he apparently drives the Pleiades before him.

Ursa Major (the Great Bear)—otherwise called "the Plough," "Charles' Wain," "the Dipper," "the Waggon," "David's Car," etc.—is by some supposed to represent the bear into which Juno changed Callisto.

Ursa Minor (the Little Bear) is supposed to have been formed by Thales, who noticed the resemblance between its seven principal stars and those of the Great Bear.

Virgo (the Virgin). This is one of the original 48 constellations, and forms one of the signs of the Zodiac. Its brightest star is called Spica, or the ear of corn in the hand of the Virgin.

We now come to the planets—

Mercury. The nearest attendant to the "King of day," and the most rapidly moving of all the planets, has been aptly named Mercury, "the swift messenger of the gods." Mercury was the son of Jupiter and Maia. One of the Pleiades is called Maia.

Venus. To the brightest of the planets,

> "Fairest of stars, last in the train of night,"

the name of the beautiful goddess Venus has been appropriately applied. There seem to have been four goddesses of this name in heathen mythology: the first was the daughter of Coelus (Uranus) and Dies; the second rose from the sea, and was the mother of Cupid (Mercury being his father); the third was the daughter of Jupiter and Dione, and was married to Vulcan; and the fourth, daughter of Tyrus and Syria, and known as Astarte; but in speaking of Venus, no distinction seems to have been made between the four by the ancient writers and poets.

Mars (the god of War) was the son of Jupiter and Juno, or, according to Ovid, of Juno alone. According to Homer, Phobos and Deimos (Dread and Terror) were attendants on Mars, and for this reason the two little satellites of the planet have received these names.

Jupiter. That the ancients were aware of the enormous size of this planet seems doubtful. However this may be, the name of the supreme God of the heathen world has been very appropriately given to the "giant planet" of the Solar System. Jupiter was the son of Saturn and Ops (or Rhea), and twin brother of Juno, whom he afterwards married.

Saturn was the son of Coelus (Uranus) and Terra (or Vesta). He married Ops (or Rhea), his own sister, and was father of Jupiter. His brother's name, Titan, has been given to the largest of Saturn's satellites. Of the other satellites, Enceladus was a giant, the son of Titan and Terra, and brother of Japetus; Zethys was the daughter of Coelus and Terra; Rhea was the mother of Jupiter.

Uranus is another name for Coelus, the father of Saturn.

Neptune, the outermost planet of the Solar System, is named after the god of the sea. He was the son of Saturn and Ops. As he was supposed to preside over horse and chariot races, Pindar calls him Hippias. Neptune was driven out of heaven, and founded the famous city of Troy.

Most of the minor planets or asteroids have been named after mythological personages, although in recent years this rule has been departed from in several cases. Of the earlier discoveries, we find that *Ceres* was daughter of Saturn and Ops (and therefore sister of Neptune), goddess of corn and tillage. *Pallas*, otherwise named Minerva, Athena, and Tritonia, is supposed to have issued fully armed from the head of Jupiter! *Juno*, sister and wife of Jupiter, was the daughter of Saturn and Ops, and therefore sister of Ceres and Neptune. *Vesta:* there seem to have been two goddesses of this name, one goddess of fire, and the other of the earth. *Astræa* was the goddess of justice. *Hebe* was the daughter of Juno. She was the goddess of youth and cupbearer to Jupiter. *Flora* was the goddess of flowers, and wife of Zephyrus. *Parthenope* was one of the Sirens.

XXIX.

THE FIGURE OF THE EARTH.

SOME curious theories were held by the ancient astronomers with reference to the figure of the Earth. Anaximander, B.C. 570, and Anaxagoras, B.C. 460, considered that the Earth was shaped like a cylinder, the known surface of land and water being situated on one of the ends of the cylinder! Plato, B.C. 400, thought that the Earth's figure was a cube, and the Chaldees believed it was shaped like an inverted boat! The fact that the Earth is of a globular form has, however, been known for over 2000 years. The author of this theory was probably Thales of Miletus, the founder of the Ionian School, who flourished in the sixth century before the beginning of the Christian era. Pythagoras, about 500 B.C., showed that the varying altitude of the stars as we approach or recede from the equator proves that the Earth is round. Parmenides of Elea is said to have taught the rotundity of the Earth about 500 years B.C. Aristarchus, writing about B.C. 280, maintained that the Earth rotates on its axis and revolves round the

Sun. Eratosthenes, who lived in the second century B.C., measured an arc of the meridian between Alexandria and Syene, probably with a view to determine the dimensions of the Earth, a method which has been adopted in modern times.

Although the globular shape of the Earth was thus recognized at an early epoch, many ages elapsed before the theory was universally accepted. Even so late as the fifth century of the Christian era we find St. Augustine vigorously maintaining that the idea of an Antipodes was an absurdity, and in recent years the late Mr. John Hampden contended to the last that the earth was shaped like a flat plate! I need hardly say, however, that the theory of a "flat earth" is for many reasons wholly untenable, and that the globular shape is now admitted by all who are gifted with even a small share of reasoning power. The proofs of the Earth's rotundity need not be repeated here. They are familiar to almost every school-boy in these days of scientific instruction. The single fact that ships disappear below the sea horizon at a distance well within the range of a telescope of even moderate power should be sufficient to convince any reasoning mind that the surface of the sea is *not* flat, but curved. We will therefore assume it as proved beyond rational doubt that the shape of the Earth is that of a sphere, or nearly so. Indeed it may be shown that the deviation of the Earth's figure from that of a perfect sphere is very small. The difference between the equatorial and polar diameters is only 26½ miles, a small quantity compared with the Earth's equatorial diameter, which is about 7926 miles. On small models this difference would be inappreciable, and even on models of considerable size the difference could not be perceived by the eye, and could only be detected by careful measurement. On a globe of 12 inches in diameter the difference would be represented by only $\frac{1}{25}$th of an inch, and even on a model of 25 feet in diameter there would be a discrepancy of only one inch between the measurements of the greatest and least diameters. In elementary works on astronomy it is sometimes stated that the Earth is flattened at the poles "like an orange," but this gives a very exaggerated idea of the Earth's polar compression, some oranges at least being very perceptibly flattened at the top and bottom. Although the deviation from a perfect sphere is small, it can, however, be easily detected by careful measurements on the Earth's surface, and some account of the researches which have been carried out with reference to the figure of the Earth may prove of interest to the reader.

In the first place it should be explained that by the figure of the Earth is meant the figure which the Earth would have if the whole of its surface were covered with water. The mean surface of the sea is therefore taken to represent the "surface of the Earth," the land and mountains being considered as elevations above, and the beds of the oceans as depressions below this mean level. These elevations and depressions are comparatively very small compared with the Earth's diameter, the altitude of the highest mountain and the depth of the deepest sea bottom being less than one-fourth of the difference between the equatorial and polar diameters. The inequalities on the surface of an orange are much greater in proportion to the size of the orange than are the highest mountain and the deepest sea to the size of the terrestrial globe. On a 2-inch globe, Mount Everest would be represented by a grain of sand less than $\frac{1}{700}$th of an inch in thickness, and even on a model of 25 feet in diameter this "monarch of mountains" would only appear as a small elevation about one-fifth of an inch in height.

To determine the dimensions of the Earth, the first thing to be done is to find by actual measurement the length of a degree on the Earth's surface. But as the length of a degree is about 69 miles, it would be too long a distance to measure directly. We can, however, measure accurately by means of wooden or iron rods a base line of five or six miles in length on a suitable level plane. From this base line we can, by a system of triangles, calculate the distance between two distant points situated on the *same* meridian. The next step is to find the latitudes of the two points. This can be done by astronomical observations with accurate instruments. The altitude of the celestial pole being equal to the latitude of the place of observation, the difference of latitude between the two points can be easily determined. This difference represents the angle at the Earth's centre which the measured arc subtends. Now dividing the distance by the angle, we obtain the length of a meridian arc of 1° of latitude. As there are 360° in the circumference of a circle, we then multiply the length of the arc by 360, and thus obtain the circumference, and from that the diameter of the Earth. If the Earth were a perfect sphere the length of arcs of 1° measured on different parts of the Earth's surface and in different latitudes should be equal. Such, however, is not the case, and hence we infer that the Earth is not an exact sphere, but differs slightly from the globular form. Measurements show that the length of an arc of 1° increases as we proceed from the equator towards the poles, which indicates that the Earth is flattened at the north and south poles.

The first attempt to determine the dimensions of the Earth by the above method seems to have been made by Eratosthenes about B.C. 230, as already referred to. Owing to the imperfection of the instruments available in those early times, his results were of course very inaccurate, but his efforts serve to show that he recognized the globular shape of the Earth. In addition to his terrestial measurements, Eratosthenes determined the obliquity of the ecliptic, or the angle between the Earth's equator and the plane of its orbit round the Sun, with considerable accuracy.

Posidonius, about B.C. 90, was the next who attempted a solution of the problem. He determined his latitudes by observations of the bright southern star Canopus, which is visible from Alexandria and Rhodes, between which places the measures were made. His result for the Earth's circumference agreed closely with that found by Eratosthenes.

Ptolemy, the author of the famous *Almagest*, and the discoverer of atmospheric refraction, writing about A.D. 160, makes the length of a degree 500 stadia, which differs considerably from the results found by his predecessors. Unfortunately we do not know the length of these "stadia," so cannot compare the result found by these early observers with those obtained by modern astronomers and mathematicians.

From the time of Ptolemy down to the fifteenth century little or no progress was made in our knowledge of the Earth's figure. In the beginning of the fifteenth century the popular idea seems to have been that the Earth was flat. But this theory was soon disputed by navigators, among whom were Columbus and Magellan; the latter especially, having sailed round the Earth, gained practical experience that the Earth is really globular. Magellan's voyage changed the current of popular opinion, and further attempts were then made to determine the Earth's dimensions.

Fernel, in 1525, calculated the length of a degree by finding the difference of latitude between Paris and Amiens, and measuring the distance between the two places. The accuracy of his result, which is remarkable—about 69 miles for one degree—must have been due to accident, as his method of measuring the distance was very rough, namely, by counting the number of revolutions which his coach-wheel made while travelling from one place to the other!

In 1617 an arc of the meridian was measured by Snellius, near Leyden. To him is due the first application of trigonometrical surveying from a base line to the determination of the distance between the extreme points of the arc to be measured. His result, however, was less accurate than that of Fernel, although obtained by a better method.

In 1633 Norwood measured an arc between London and York, the first attempt made in England to determine the length of a degree.

In 1671 Picard and La Hire published the result of their measurement of a meridian arc between Paris and Amiens. The work was carried out with great care and attention to scientific precision, and the distance was deduced from trigonometrical measures starting from a base line of nearly seven miles in length. Although the modern corrections necessary for refraction, aberration, etc. were then unknown, the result is wonderfully accurate, namely, 69¾ miles to one degree, which is slightly in excess of the mean value given by Bessel—69·043 miles.

In all the previous determinations it was assumed by the investigators that the figure of the Earth was that of a perfect sphere, and this opinion seems to have been held till nearly the close of the seventeenth century. But early in the eighteenth century, J. Cassini and J. D. Cassini showed that in the various measures of meridianal arcs there were discrepancies which could not be satisfactorily accounted for by errors of observation, and that these discordances indicated that the Earth's figure was not that of an exact sphere. Richer, in 1671, observing at Cayenne, found that a pendulum beating seconds at Cayenne was slightly shorter than a seconds pendulum at Paris. This fact Huygens explained by supposing a protuberance at the Earth's equator, and hence a flattening at the poles. On this hypothesis the figure of the Earth measured along a meridian would not be an exact circle, and this deviation from a perfect circle might be found to explain the discrepancies in the measured arcs of the meridian at different places on the Earth's surface.

The spherical theory having been thus shown to be untenable, the next most probable hypothesis was that the Earth's figure is that of a spheroid of revolution. If an ellipse be supposed to rotate round its minor or shorter axis, a solid is generated called an *oblate spheroid.* If the rotation takes place round the major or longer axis, the resulting solid is termed a *prolate spheroid.* Pendulum experiments having shown that the Earth's polar axis of rotation is shorter than the equatorial diameter, it was provisionally assumed that the Earth's figure was that of an oblate spheroid. Mathematical considerations also showed that this was the figure which a rotating body would naturally assume. In the case of the planets Jupiter and Saturn, in which the velocity of rotation is much greater than the terrestrial rotation, the compression at the poles considerably exceeds that of the Earth, and indeed this flattening can be easily detected by the eye, without micrometrical measurement.

The decrease in the force of gravity at the Earth's equator, as indicated by the pendulum, is, of course, *partly* due to the effect produced by the so-called centrifugal force of the Earth's rotation; but this being duly allowed for, Sir Isaac Newton showed in his *Principia* that the effect of the Earth's rotation on its axis would be to produce an oblate spheroid. Newton's calculations were, however, based on the assumption that the Earth may be considered as homogeneous, that is of the same density from the surface to the centre. On this hypothesis he obtained an ellipticity or flattening of $\frac{1}{230}$, a value which actual measurements show to be too large. Clairaut subsequently considered the subject on the hypothesis that the Earth's density increases towards the centre, and obtained much better results. Observations have shown that the weight of a body at the Earth's poles would exceed the weight of the same body at the equator by about $\frac{1}{187}$th part of the whole weight; that is, a body weighing 187 lbs. at the equator would weigh 188 lbs. at the pole. Clairaut showed by mathematical analysis that the sum of the fractions representing the ellipticity and that representing the increase of gravity at the poles will be equal to $\frac{5}{2}$ of the ratio between the centrifugal force at the equator and the force of gravity.

Now, knowing the dimensions of the Earth and the time of rotation on its axis, we can calculate the amount of the centrifugal force at the equator, and this comes out $\frac{1}{289}$. Hence we have by Clairaut's theorem the equation (e = Earth's ellipticity)

$$e + \frac{1}{187} = \frac{1}{289} \times \frac{5}{2} = \frac{1}{115{\cdot}6}$$

$$\text{Whence } e = \frac{1}{302{\cdot}7}$$

—a value which agrees closely with the results of actual measurement.

It may be here explained that the fraction representing the ellipticity or flattening at the poles is found by subtracting the polar diameter from the equatorial, and dividing the difference by the equatorial diameter. The difference of the diameters in the terrestrial spheroid is about 26½ miles.

Several measurements of arcs were made in the eighteenth century by Maupertius, Clairaut, Le Monnier, and others, and the results showed that the Earth is an oblate spheroid.

Combining all the available data, the dimensions of the terrestrial spheroid were computed by Bessel and Clarke. Bessel in 1841 found the equatorial diameter of the Earth to be 7925·52 miles, and the polar diameter 7899·03 miles, indicating a compression or ellipticity of $\frac{1}{299}$.

In 1859 General de Schubert suggested that the discrepancies in the data might be reconciled by supposing the figure of the Earth to be not an exact spheroid of revolution, but a figure known as an *ellipsoid*, that is a solid in which the plane passing through the centre at right angles to the shorter axis is not a circle, but an ellipse. On this hypothesis the Earth would have *three* axes of different lengths at right angles to each other. The lengths of these three axes were computed by General de Schubert, and afterwards by General Clarke. The great physical improbability of the Earth having a figure of this kind has, however, led mathematicians to reject the ellipsoidal hypothesis and to attribute the apparent deviations from the true spheroidal figure to the effects caused by local attraction of mountains, etc. on the plumb-line of the instruments used in determining the latitudes.

In 1880 General Clarke abandoned the ellipsoidal hypothesis and reverted to the theory of an oblate spheroid. Using data derived from arcs measured in Russia, India, the Cape of Good Hope, Peru, and the Anglo-French arc, he arrived at the following results—

	Feet.	Miles.
Earth's equatorial diameter	= 41,852,404	= 7926·59
„ polar „	= 41,709,790	= 7899·58

$$\text{Flattening} = \frac{1}{293{\cdot}47}$$

From a discussion of all the available data Professor Harkness found in 1891 the following results—

$$\text{Equatorial diameter} = 7926{\cdot}248 \pm 0{\cdot}156 \text{ miles}$$

$$\text{Polar} \quad „ \quad = 7899{\cdot}844 \pm 0{\cdot}124 \quad „$$

$$\text{Flattening} = \frac{1}{300{\cdot}205 + 2{\cdot}964}$$

Pendulum experiments since 1830 give value for the flattening ranging from $\frac{1}{280{\cdot}10}$ to $\frac{1}{302{\cdot}76}$, the mean of 14 determinations being $\frac{1}{289{\cdot}6}$, and Professor Harkness concludes from these experiments that "either the flattening must lie between 1 : 296 and 1 : 300, or the distribution of density within the Earth cannot be represented by any function which increases continuously from the surface to the centre." Considering the results derived from all the methods of calculation, including those from precession and nutation, and the perturbations of the Moon, he considers that "the facts thus far adduced scarcely warrant any conclusion more definite than that the flattening lies between 1 : 290 and 1 : 300, but with some further evidence which tends in the direction of the smaller limit."

The comparatively close agreement, however, between the results found by different methods shows clearly that the spheroidal theory is correct. We may therefore conclude that the figure of the Earth is practically an oblate spheroid of revolution with a flattening or ellipticity of about $\frac{1}{300}$.

XXX.

THE VARIATION OF LATITUDE.

To most people, even those familiar with the facts of astronomy, the latitude of any place on the Earth's surface would probably be considered as an invariable quantity, constant at all periods of the year, and the same for every year. To mathematicians accustomed to discuss and calculate the rotation of a rigid body—as the Earth is supposed to be—the constancy in position of the Earth's axis of rotation would be taken for granted.

And, indeed, for all practical purposes it might be justly concluded that the latitude does not vary. Ordinary observations would show that the celestial pole maintains a constant elevation above the horizon, this elevation, or altitude, being equal to the latitude of the place of observation. Careful measures, however, made during a long series of years at various astronomical observatories have shown that the latitude is really subject to a small variation, which becomes of considerable importance when the modern refinement of astronomical calculations is considered.

In a remarkable series of papers, published in 1892 and 1893, by the well-known American astronomer Mr. S. C. Chandler, he gives the results of his researches on this interesting subject. His first suspicion of a periodical change of latitude seems to have been aroused some eight years ago, when observations with his newly-invented almucantor appeared to indicate a change of latitude. The correctness of this result was apparently so improbable that Mr. Chandler merely published his observations, and waited paitently for further evidence in support of this startling discovery. In the year 1888 Dr. Kustner found similar irregularities in his observations of latitude, and these were confirmed by observations made at several observatories on the continent of Europe.

Encouraged by these results, Mr. Chandler then resolved to rigorously attack the problem, and adopting a provisional period of 400 days for the supposed variation in latitude, he analyzed a long series of observations made at observatories between the years 1726 and 1887. His investigations—which involved the manipulation of an enormous number of figures—showed evidence of variation of the latitude, due, he considers, to a rotation of the Earth's axis from west to east in a period of about 427 days, and in a circle having a radius of 30 feet measured on the Earth's surface. In other words, his results indicate that the Earth's axis of rotation does not coincide with the axis of inertia.

From a further investigation this preliminary result was somewhat modified. The observed variation was found to be the result of two periodical variations, one with a period of about 427 days, the other having a period of one year. These two fluctuations sometimes combine their effects, and at others tend to neutralize each other. The maximum effect of the annual variation occurs about the time of the autumnal equinox (Sept. 23), and the minimum about the vernal equinox. The maximum combined effect of the two variations may amount to about 0·6 of a second of arc.

From observations of circumpolar stars made at the Greenwich Observatory in the years 1851 to 1891, Messrs. Thackeray and Turner find results which tend to confirm those of Mr. Chandler, and afford strong evidence in favour of his theory.

Concerted observations made at Berlin, Potsdam, and Prague in the years 1889—1891 fully confirm the variation in latitude. They indicate a fluctuation of about half a second of arc annually, and the observations are wonderfully accordant.

Mr. Chandler's conclusions are supported by such eminent astronomers as Professor Simon Newcomb and Dr. B. A. Gould, at least as far as the present period of variation is concerned. Mr. Chandler's investigations show that, although the period is now 427 days, it was less than one year about the year 1770. Professor Newcomb, however, maintains that the length of the period must be invariable, and he refers to the elasticity of the Earth as a possible physical explanation of the latitude variation.

It has been suggested that the variation in latitude may, perhaps, be due to a meteorological effect; that is, that it may possibly be caused by periodical changes in the arrangement of the atmospherical strata, which would of course affect the refraction, and hence the astronomical observations. But if this were so, we should expect the variation to show an annual period, and not one of some 14 months. Dr. Herz suggests a theory which connects the variation with an electrified state of the Sun. He supposes the Earth not to be a perfect conductor, and the air an imperfect non-conductor, and he shows that the direction of gravity (or the direction of the plumb-line) will be subject to an apparent change, which would affect the observations of latitude.

Whatever the physical cause may be of this unexpected variation in the latitude, it seems demonstrated beyond a doubt that a small periodical change does take place.

At first sight it may seem that the observed variation is so small that it might be neglected for all practical purposes. For geodetical operations this may be true, but for the refined requirements of astronomy, such a variation in latitude—formerly assumed to be invariable—vitiates the determination of various astronomical constants, the computation of which was based on the assumption of a constant zenith. Some of the constants thus affected are, the equinoctical points, the obliquity of the Ecliptic, the constant of aberration, the measures of parallax, the system of right ascensions and declinations, and possibly, to a small extent, the constants of precession, nutation, and refraction.

The constant of aberration of the stars (an apparent effect due to the Earth's orbit round the Sun, combined with the progressive motion of light) was for many years considered by astronomers as known with great accuracy, the only doubt being as to the value of the second place of decimals (the value ranging between 20·447″ and 20·492″ as determined by different computors). Owing to the discovery of the latitude variation, however, Mr. Chandler thinks that even the value of the first decimal is now called in question. Making due allowance for the variation of latitude, he deduces from Peters' observations of the Pole star in the years 1842-44 a value of 20·510″ for this important astronomical constant. He also thinks that "hitherto unexplained discordances among the various determinations" of the equinoctial point, or zero-point of right ascensions, may be reconciled by making due allowance for the variation of latitude. Combining the value given above for the constant of aberration with Newcomb's determination of the velocity of light, he finds the solar parallax to be 8·785″.

XXXI.

THUNDERSTORMS AND AURORAS.

In some very interesting papers recently read before the Academy of Sciences, Rochester (U.S.A.), Dr. M. A. Veeder gives the results of his researches on Thunderstorms, Auroras, and the Zodiacal Light. He finds that Auroras tend to recur at intervals of a synodical rotation of the Sun on its axis, which is about 27 days, 6 hours, and 40 minutes. The Sun really rotates in a period of about 25¼ days, but owing to the Earth's orbital motion round the Sun in the same direction as the Sun's rotation, this period is *apparently* lengthened to about 27¼ days. The Sun's axis of rotation is inclined to the plane of the Ecliptic—the plane of the Earth's orbit—at an angle of about 83°, and consequently the Sun's Northern Hemisphere sometimes leans towards the Earth, and sometimes his Southern Hemisphere.

Dr. Veeder finds that in general "Auroras and their attendant magnetic storms occur when spots or faculæ, or both, are at the Sun's eastern limb, and near the plane of the Earth's orbit." He also finds that the recurrence of Auroras is not continuous, but that they occur more frequently near the equinoxes (March 21 and September 23), the phenomena almost disappearing near the solstices (June 21 and December 22). He has also discovered that thunderstorms show a tendency to take the place of Auroras when the latter fail to appear, and he concludes from this relation that both phenomena have their origin in electrical action between the Sun and the Earth. There is, however, a slight difference between the conditions favourable to the production of the phenomena. It appears that thunderstorms generally take place when the disturbed portions of the Sun are at the eastern limb and "at a distance from the plane of the Earth's orbit," while Auroras usually occur when spots and faculæ are close to the same plane.

Dr. Veeder finds that thunderstorms usually occur in the afternoon, with a "secondary maximum between midnight and morning." Thunderstorms are of such frequent occurrence in India that it has occurred to me to test Dr. Veeder's theory by the meteorological records of that country. With this view I have carefully examined the records of thunderstorms as given in the Madras Meteorological Results for the years 1861—1890, and I find a well-marked tendency to occurrence in the afternoon and early morning hours. They also show a tendency to occur with greater violence near the equinoxes than at other times. The following are the dates of *severe* thunderstorms during the thirty years of observation at Madras Observatory—

1863	July 10	"heavy thunderstorm"
1871	Sept. 27	"heavy"
1873	Oct. 3	"heavy"
1876	April 30	"heavy"
1879	Oct. 8	"severe thunderstorm"
1880	Sept. 9	"heavy"
1881	Aug. 6	"heavy"
1884	Oct. 16	"heavy"
1886	Oct. 31	"heavy"
1887	Sept. 29	"heavy"
1887	Oct. 9	"cyclone and thunderstorm"
1890	July 26	"heavy"

Of these 12 great thunderstorms, nine occurred not far from the equinoxes. Of the three exceptions, two took place in July, about the beginning of the monsoon (or yearly rain season), when the atmospheric conditions are usually much disturbed. There seems, therefore, to be strong evidence in favour of Dr. Veeder's conclusions. In the year 1880, thunderstorms occurred on July 19 at 5½ p.m., and on August 15 at 8 p.m., the interval being 27 days 2½ hours—in close agreement with the period of the Sun's synodical revolution—and again on Oct. 4 and 31, an interval of 27 days.

Records of Auroras in the United States tend to confirm the truth of Dr. Veeder's hypothesis. Thus, Auroras were visible in the year 1892 on January 5, February 2, February 29, March 27, and April 23, or at intervals of 27 days, and "associated with reappearances at the Sun's eastern limb of an area south of the equator which has been much frequented by spots and faculæ."

Dr. Veeder advances a new view of the Zodiacal Light which has long been an enigma to astronomers. He considers that the light is an extension of the solar corona, and "is probably double, corresponding to the bifurcation seen during eclipses, each section overlying a sun-spot belt. In the spring months, the south pole of the Sun being turned towards the Earth, the southern section is seen edgeways and becomes invisible (like Saturn's rings), the northern section being at the same time opened out to its widest extent, and reflects far more light earthward than at any other time." The light is then seen after sunset. This state of things is reversed in the autumn, when the southern section becomes visible before sunrise. In winter and summer "the Earth occupies a position intermediate between these disc-like coronal extensions," and consequently the Zodiacal Light is less conspicuous. Dr. Veeder is of opinion that the Zodiacal Light consists of ferruginous particles, and that it is the medium by which magnetic phenomena are transmitted from the Sun to the Earth. If Dr. Veeder's theory is correct, we should expect to find some relation between the periodical development of sun-spots and the phenomena of Auroras and magnetic storms, and such a connection has been actually shown by observation, the number of Auroras and magnetic disturbances being more frequent in the years of sun-spot maxima.

XXXII.

THE BAROMETRIC MEASUREMENT OF HEIGHTS.

THERE are several methods of measuring the heights of mountains and other elevated portions of the Earth's surface above the sea-level. Of these may be mentioned the following: (1) By actual levelling with an engineer's spirit-level and graduated staff; (2) by trigonometrical calculation based on the measurement of the angles of elevation observed at the extremities of a carefully-measured base line; (3) by observing the temperature of the boiling-point of water; and (4) by reading a barometer at the sea-level, and again at the top of the mountain or elevation, the height of which is to be determined.

The first of these methods is certainly the most accurate, but it involves a considerable amount of labour, and for very high mountains is sometimes impracticable. The second method is sufficiently accurate, if carefully carried out, and a nearly level plain is available for the measurement of a base line. The third method is not accurate enough to give reliable results. The fourth is the simplest and most expeditious of all. It is especially useful for finding the difference of level between two points at considerable distances apart, and would be sufficiently accurate if certain difficulties could be successfully surmounted. A consideration of this method, and the difficulties to be overcome, before its accuracy can be relied upon, may prove of interest to the general reader.

The principle of the barometric method is as follows: The barometer measures the weight or pressure of the atmosphere. The column of mercury in an ordinary mercurial barometer is equal in weight to a column of air of the same diameter, and of a height equal to that of the Earth's atmosphere. The densest portion of the atmosphere is that close to the Earth's surface, and its density diminishes as we ascend. At the top of a mountain, therefore, the pressure of the atmosphere will balance a shorter column of mercury, and hence the mercury descends in the tube. From the difference in height of the mercury at the level of the sea, and on the top of the mountain, it is possible to calculate the height we have ascended, as will be shown further on.

There are two forms of barometers, namely, the mercurial barometer and the aneroid. Of mercurial barometers, there are two forms, the "cistern" and the "syphon." The cistern form is the one generally used for scientific observations, and is the best for measuring heights. One of the most approved forms of cistern barometers—known as "Fortin's barometer"

—consists of a glass tube, closed at one end, and filled with mercury, the lower portion of which dips into another tube of larger diameter, which contains a reservoir of mercury forming the "cistern." The bottom of the cistern is formed of leather, and fitted with an adjusting screw below, for the purpose of adjusting the level of the mercury in the cistern to an ivory index point, which marks the zero of the graduated scale used for reading the height of the mercurial column. By means of this adjusting screw the mercury may also be raised so as to completely fill the cistern and tube, and thus adapt the instrument for travelling.

We need not discuss here the manufacture of barometers, and the filling of the tube with mercury, an operation which must be performed carefully so as to exclude air from the tube. Suffice it to say, that the best method is to fill the tube gradually, and boil the mercury as we proceed by means of a spirit-lamp, in order to drive out all bubbles of air which may be contained in the mercury. The tube may be filled without boiling, but the resulting instrument will not be so accurate as one in which the mercury has been boiled.

To determine the difference of elevation between two places with a mercurial barometer, several points must be attended to. In the first place, the temperature of the barometer and the temperature of the air must be noted at each station. As the mercury in a barometer is affected by heat—in the same way that a thermometer is—the temperature at which the barometer is read must be observed. For this purpose a thermometer is usually attached to the barometer. The temperature should be read as accurately as possible, for an error of one degree Fahrenheit would make a difference of about three feet in the resulting altitude. The reading of the attached thermometer should be first noted, and then the height of the barometer. To do this, first bring the surface of the mercury in the cistern accurately to the index-point by means of the adjusting screw. Then tap the tube gently near the top of the column in order to get rid of the adhesion between the mercury and the glass. The height of the mercury may then be read by means of the attached scale and vernier. Sometimes the amount of aqueous vapour in the atmosphere is ascertained by another instrument. The above data being known for two stations, we substitute the values found in one of the barometric formulæ, and thus obtain the height or difference of height required. Before the barometer readings can be used, they must be reduced to the same temperature—usually 32 degrees Fahrenheit.

Various formulæ have been computed by eminent mathematicians and physicists for calculating the difference of height between two points. These formulæ depend on certain assumptions, which, however, cannot be considered as rigidly true. The most important of these assumptions is, that the atmosphere may be considered to be in a state of statical equilibrium. But owing to the changes constantly taking place, due to differences of temperature, humidity, winds, etc., this assumption cannot be considered as correct. The result will therefore be only an approximation to the truth. Assuming, however, a statical equilibrium of the atmosphere, a formula can be easily deduced from known principles. For this purpose we must first ascertain the weight of a cubic inch of air and a cubic inch of mercury at a certain temperature and pressure, and in a given latitude, say 45°. Then, by Boyle and Marriotte's law connecting the weight of a gas and the pressure, a formula can be found for determining the height required. There are several elaborate formulæ used for the purpose. These include terms for altitude, latitude, temperature, and humidity. A correction for altitude is theoretically necessary, owing to the diminution in the force of gravity—and, therefore, a decrease in the weight of bodies—with increased distance from the centre of the Earth, but this correction is comparatively very small, and may, for all practical purposes, be neglected. For the same reason a correction for latitude is mathematically required, owing to the spheroidal figure of the Earth; but this, too, is very small, and may be safely neglected. The correction for temperature of the *air* is, however, very important. This term is easily computed. It is obtained—for the Fahrenheit scale—by deducting 64 from the sum of the observed temperatures at the upper and lower stations, dividing the difference by 900, and adding unity to the result. A correction for the humidity of the air is also necessary; but it is doubtful whether it is desirable to complicate the formula by a correction for atmospheric moisture, the laws of which are so imperfectly understood.

In all the barometric formulæ which have been proposed, the first term is constant and common to all. It is known as the "barometric co-efficient," and is $5·744\frac{m}{a}$, where *m* is the "weight of a cubic inch of mercury at the sea-level in latitude 45° at 30° Fahrenheit, when the barometer reads 29·92 inches," and *a* the weight of a cubic inch of dry air under the same conditions of latitude, temperature, and pressure. Various values of this constant have been found, depending on the values assumed for *m* and *a*. Arago and Biot found $\frac{m}{a} = 10{,}467$. This makes the "barometric co-efficient" 60,122·4 feet. Raymond's value, namely 60,158·6 feet, was found by comparing the values given by the formulæ with the results of actual levelling with a spirit-level. His observations were, however, few in number, and although his co-efficient is often used, it is probably the least accurate of all the determinations. In Laplace's formula Raymond's constant is used. Babinet used the constant 60,334, and in Baily's formula the constant is 60,384, which is the value found by

Regnault, and is probably the most accurate of all. Sometimes the co-efficient in the formula is given as 10,000 *fathoms*, which is roughly correct.

We will now consider the errors underlying the barometric measurement of heights, and which render the method inapplicable in cases where great accuracy is required. The most important of these sources of error is probably that due to what is called the "barometric gradient," a term frequently used in meteorological reports. Taking three points at which the barometric pressure is the same; if the atmosphere was in a state of statical equilibrium these points would lie on the same level plane. But usually this plane is not level but inclined, and the inclination of the plane is termed the "barometric gradient." For a *number* of points the surface on which they lie would not be a plane at all, but an undulating surface. These surfaces for different heights are never parallel, and frequently slope in opposite directions. Allowance cannot be fully made for this disturbing cause, but the error can to some extent be eliminated by making a number of simultaneous observations at the two stations and taking a mean of the results.

Another cause of error is due to variations in the temperature of the air. It is generally assumed that the mean temperature of the column of air between two stations, one vertically over the other, is the mean of the temperatures at the upper and lower stations; but this is not always the case. The error may be partly eliminated by making observations at intermediate stations, but cannot be entirely overcome. High winds also cause a variation in the height of the barometer.

In addition to the errors mentioned, there are, of course, errors of observation and instrumental errors. The former may be caused by imperfect adjustment of the zero-point and erroneous reading of the mercury on the scale. These errors are, however, usually small, and may with care be neglected. The instrumental errors are chiefly due to imperfect graduation of the scales of the barometer and attached thermometer, impurity of the mercury, and to air in the tube. These errors may be corrected by comparison with a standard instrument.

The form of barometer known as the aneroid is also frequently used for the determination of heights, a graduated scale being added for that purpose. This scale is graduated by means of one of the barometric formulæ already referred to. The aneroid barometer usually consists of a metallic box from which the air has been exhausted, and differences of atmospheric pressure are recorded by a system of levers which act on an index-hand which marks the reading on a graduated scale. In some forms of aneroid the box is not completely exhausted of air, and these are called "compensated aneroids," but the name is misleading, some of these instruments being more sensitive to changes of temperature than those not compensated. The aneroid is a very handy instrument and easily used, but for the purpose of measuring heights it is much inferior to the mercurial barometer. In some aneroids the altitude scale is fixed at a certain reading, say 30 or 31 inches, and in others it is movable, and can be adjusted to any reading required. The latter seems the most convenient plan. In either case it is clear that absolute elevations above the sea-level cannot be determined with this instrument with any approach to accuracy, as there is no way of making the necessary corrections for variations of pressure, temperature, etc. The aneroid barometer should, therefore, be used only for finding *differences* of elevation, and for this purpose it will give fairly good approximate results in cases where extreme accuracy is not required.

To show the degree of accuracy attainable by the barometric method, two examples may be cited. From readings of a mercurial barometer at the summit of Mont Blanc and at the Geneva Observatory made by Messrs. Bravais and Martins in the year 1844, the height of the mountain above the level of the sea was computed to be 4815·9 metres, or 15,800·44 feet. Corabeuf found by trigonometrical measurement a height of 15,783 feet, or 17·44 feet less than that indicated by the barometer.

The height of Mount Washington in the United States was found by a spirit-level to be 6293 feet above sea-level, while the barometric method gave 6291·7, a close approximation. In some cases, however, much larger differences have been found, and the good agreement quoted above may perhaps be considered as accidental.

XXXIII.

THE OBSERVATORY ON MONT BLANC.

THE bold idea of founding a Meteorological Observatory on the summit of the highest mountain in Europe is due to the famous French astronomer, M. J. Janssen, who made an ascent of Mont Blanc in the year 1890, to enable him to judge of the possibility of such an undertaking. Having come to the conclusion that the project was feasible, M. Janssen made an appeal for funds, and numerous generous donations were subscribed for the purpose. A committee was then formed, of which the President of the French Republic was an honorary member, and which included the names of Prince Roland Buonaparte, Baron Alphonse de Rothschild, M. Bischoffseim and others.

The first thing to be considered was, of course, the possibility of obtaining the necessary foundations for the proposed building. The summit of Mont Blanc consists of a thick cap of ice or frozen snow, of unknown depth; and to ascertain, if possible, the thickness of this permanent crust, borings were made near the summit, with the hope of reaching the solid rock. These shafts, which were about 15 feet long, and about 27 feet vertically below the actual summit of the mountain, were driven horizontally at an angle of 45°, but failed to meet with any rock. The idea then occurred to M. Janssen that it might perhaps be possible to found the building on the ice itself, which observations have shown to be subject to merely small and periodical changes. To ascertain whether the ice-cap would be sufficiently strong to bear the weight of a building, experiments were made in France. A mound of snow of the proposed height of the first floor was piled up during the winter at the Meudon Observatory, in such a way as to have the same density as that which covers the summit of Mont Blanc, at a depth of 3 to 6 feet below the surface. This density is, according to the measures of Lieutenant Dunod, about half that of water. The summit of this mound having been levelled off, it was loaded with discs of lead, each about 14 inches in diameter, and weighing about 66 lbs. When a column of 12 discs had been raised, weighing about 792 lbs., they were removed, and the depth of the impression made in the snow was measured. This amounted to less than one-third of an inch, a compression unexpectedly small, and proved that the ice-cap on the summit of Mont Blanc was abundantly strong for the support of a building about 33 feet long by 16½ feet wide, which it was proposed to erect.

The stability of the foundation being thus demonstrated, it was necessary to consider the form of building most suitable to resist the violent storms which are of frequent occurrence on the summit of the mountain. The form of a truncated pyramid was selected, with the lower storey of the building buried in the snow. These preliminary investigations having been completed, it was decided to proceed with the construction of the building, and a suitable edifice was designed of the above form by an eminent architect, M. Vaudremer. The building is of two storeys, with a terrace and balcony, the lower storey being entirely below the surface of the snow. A spiral staircase runs the whole height of the building, connecting both storeys with the terrace, and rising above it several feet for the support of a small platform for meteorological observations. The walls are double, to protect the observers from the cold, and the windows and openings are provided with outside shutters which fit very closely. The building is furnished with heating apparatus and all the necessary accessories for life at this high altitude.

The Observatory was then constructed and conveyed in pieces to Chamounix. About three-fourths of the materials were at the end of 1892 transported to the summit of the Grands Mulets, a height of about 9800 feet, and about a quarter to the Rochers Rouges (about 14,800 feet). The Observatory was practically completed towards the close of the year 1893. The

Observatory will be of an international character, and all observers who wish to visit it will be cordially welcomed.

M. Janssen made another ascent of Mont Blanc in September 1893, in order to inspect the Observatory, and to make some observations on the solar spectrum with reference to the disputed question of the existence of oxygen in the Sun. The observations were made with a grating spectroscope by Rowland on the B group of lines of the solar spectrum. This group includes a series of double lines, 13 or 14 doublets being visible at the surface of the sea. M. Janssen found that at Chamounix the thirteenth doublet was difficult to see. At the Grands Mulets, only the tenth or eleventh pair could be seen. Finally, at the summit of Mont Blanc, M. Janssen could hardly see beyond the eighth pair, and from these observations he concludes that all the lines in the B group would disappear from the solar spectrum near the limits of the Earth's atmosphere. The conclusion then is that these lines, which are due to oxygen, are produced solely by the Earth's atmosphere, and that oxygen does not exist in the Sun.

THE END.

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